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CRETACEOUS STRATIGRAPHY OF CENTRAL ANDES OF PERU[1]

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ABSTRACT

Cretaceous facies in Peru commonly fall into a lower, mainly clastic, group of formations and an upper group consisting of limestones, dolomites and shales. The clastic formations are largely non-marine. Over much of the country they range in age from Valanginian to Late Aptian or Albian, though in eastern Peru they extend into the Upper Cretaceous. The basal part of the limestone and shale group of formations is commonly Albian in age, though it is younger in the east. Tuffs and flows form an important part of the Cretaceous sequence of coastal Peru, but are not common elsewhere in the country. These Cretaceous units are overlain by redbed formations, some of which may be as old as the Campanian. The relationships between the redbeds and the underlying units range from conformity to slight angular unconformity.

The Cretaceous formations range in thickness from about 3,000 meters on the western flank of the Andes and 2,000 m. in eastern Peru to 1,000 m. or less in the intervening region. On this basis the Andean belt is believed to have consisted of two troughs (the West Peruvian trough and East Peruvian trough of this report) separated by a relatively positive area called the Marañon geanticline.

The clastic sequence in the West Peruvian trough was probably derived from the geanticline and from tectonic lands on the southwest. The clastics in the East Peruvian trough were contributed by the Brazilian shield, and probably by the geanticline.

Although there were temporary marine advances into the troughs during the Neocomian and Aptian the main transgression did not begin until the Albian. The West Peruvian trough and the Marañon geanticline were submerged by the Medial Albian, and marine conditions began to spread into the northern part of the East Peruvian trough. The latter was not completely submerged, however, until the sea reached its greatest extent during the Coniacian.

Although there was Late Albian tectonism in parts of the Andean belt, widespread emergence did not begin until the Santonian or Campanian, when the West Peruvian trough was uplifted. Subsequently the whole of the belt was folded and uplifted by orogenic phases which took place possibly in the Miocene and Pliocene.

The Andean belt in central Peru may be divided into structural provinces, which are from southwest to northeast: Paleozoic massifs; gently folded and block-faulted Mesozoic sediments and volcanics; batholith; strongly folded Cretaceous formations; folded and metamorphosed Paleozoic formations overlain by gently folded Mesozoic and Cenozoic formations; and moderately folded Mesozoic and Cenozoic formations.

Introduction

The present study was undertaken in order to determine the age, nature, and origins of the Cretaceous formations of central Peru and their relations to formations of similar age in other parts of the country. Particular attention was paid to the nature of the Upper Cretaceous carbonate rocks, and to the petrology and directional sedimentary structures of the pre-Albian sand-

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[2] Comisión de la Carta Geológica Nacional.

The writer is indebted to J. V. Harrison of Oxford University for first directing his interests toward the field of Andean geology. His geological maps of parts of the Central Andes are the only ones available, and greatly facilitated the field work for this report.

The field work was made possible by the financial assistance and hospitality of the following companies: Cerro de Pasco Copper Corporation, Cerro de Pasco Petroleum Corporation, Compania Peruana de Petroleo "El Oriente," Compania de Petroleo Ganzo Azul Ltda., Compania de Petroleo Shell del Peru, International Petroleum Company Ltd., Latin American

stones. The stratigraphic data were used to obtain a clearer understanding of the tectonic framework of Peru during the Cretaceous. The stratigraphic data are summarized briefly in the Appendix.

Brief descriptions of the measured sections may be found in the Appendix. More complete descriptions will be published in the Boletín of the Sociedad Geológica del Peru.

PREVIOUS WORK

Although exploitation of the mineral resources of the Peruvian Andes has been going on for some time there have been relatively few attempts at regional stratigraphic studies. McLaughlin (1924) made an excellent summary of what was then known of the stratigraphy of the Peruvian Central Andes, a region in which Harrison (1940, 1943, 1951a, 1951b, 1953, 1956a, and 1956b) has since carried out an extensive program of geological mapping. Other studies include those of Kummel (1948) on a large area of eastern Peru; Fischer (1956) on northwestern Peru; Jenks (1948) on the Arequipa region; Newell (1949) on the region about Lake Titicaca; and Benavides (1956) on the Northern Andes.

GEOGRAPHY

Peru lies astride the Andean chain between the Equator and Latitude 18° South. The country is conventionally divided into three natural regions which are, from southwest to northeast, the low Coastal Region, the mountainous Andean Region, and the broad river valleys of the Eastern Lowlands.

Mines Ltd., Mobil Oil Company del Peru, Peruvian Gulf Oil Company, Peruvian Oils and Minerals Ltd., Petroleo Sullana Ltda., Petrolera Peruana S.A., Richmond Oil Company.

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The laboratory work was carried out in the Department of Geology, Harvard University. The report was submitted in partial fulfilment of the requirements for the degree of Ph.D. The faculty and graduate students of this department were generous in their assistance to the writer throughout his stay. The writer is particularly indebted to Professor Bernhard Kummel for many discussions on the problems of Andean geology and for helpful criticisms during the preparation of the report. The manuscript was also read and criticized by Professor Raymond Siever and Professor Marland P. Billings. The opinions expressed are, however, those of the writer.

The Coastal Region is a narrow strip of desert between the Pacific Ocean and the Andean Region. There is a narrow coastal plain in parts of northern and southern Peru, but in the central part of the region spurs extend from the Andes almost to the shoreline. Throughout the Coastal Region vegetation is meager or non-existent except where mountain streams provide water.

The Andean Region is a belt of highlands about 200 km. broad. In central Peru it consists of a plateau with a mean elevation of about 4,000 m. bounded both on the east and the west by high cordilleras. Much of the Western Cordillera exceeds 5,000 m. in elevation, and several peaks rise more than 6,000 m. above sea-level. The Eastern Cordillera is generally lower, though elevations of 5,000 m. are not uncommon. Whereas the plateau has a gently rolling topography the flanks of the Cordilleras are deeply dissected. Steep canyons have been eroded to depths of more than 1,000 m. The vegetation varies from an incomplete cover of tussocky grass at high elevations to thorn scrub or jungle at lower altitudes. The nature of the exposures depends on the elevation. Above 4,000 m. the Cordilleras show abundant evidence of Pleistocene glaciation, and exposures are excellent. Beneath that elevation the valley sides have a mantle of soil and terrace material, and good sections can be obtained only along ridge tops and stream courses.

The Eastern Lowlands extend from the Andean foothills into the broad river valleys of the Amazon basin. They are in contrast to the Andean region in every way, and are characterized by heavy precipitation, continuous high temperatures, and abundant vegetation. The broad river valleys lie at elevations of 300 m. or less, and the watersheds do not usually rise above 1,000 m.

The area of central Peru considered in this report lies between Latitudes 9°30′ South and 12° South, and extends from the Pacific Ocean eastward beyond the Continental Divide. It includes those parts of the Coastal and Andean Regions of central Peru (Fig. 1).

FIELD TECHNIQUE

The field work for this report was carried out in the summers of 1958 and 1959. Stratigraphic sections were located by driving over all available roads, and by travelling with animals over the extensive areas which could not be reached by vehicles. The locations of the sections are shown

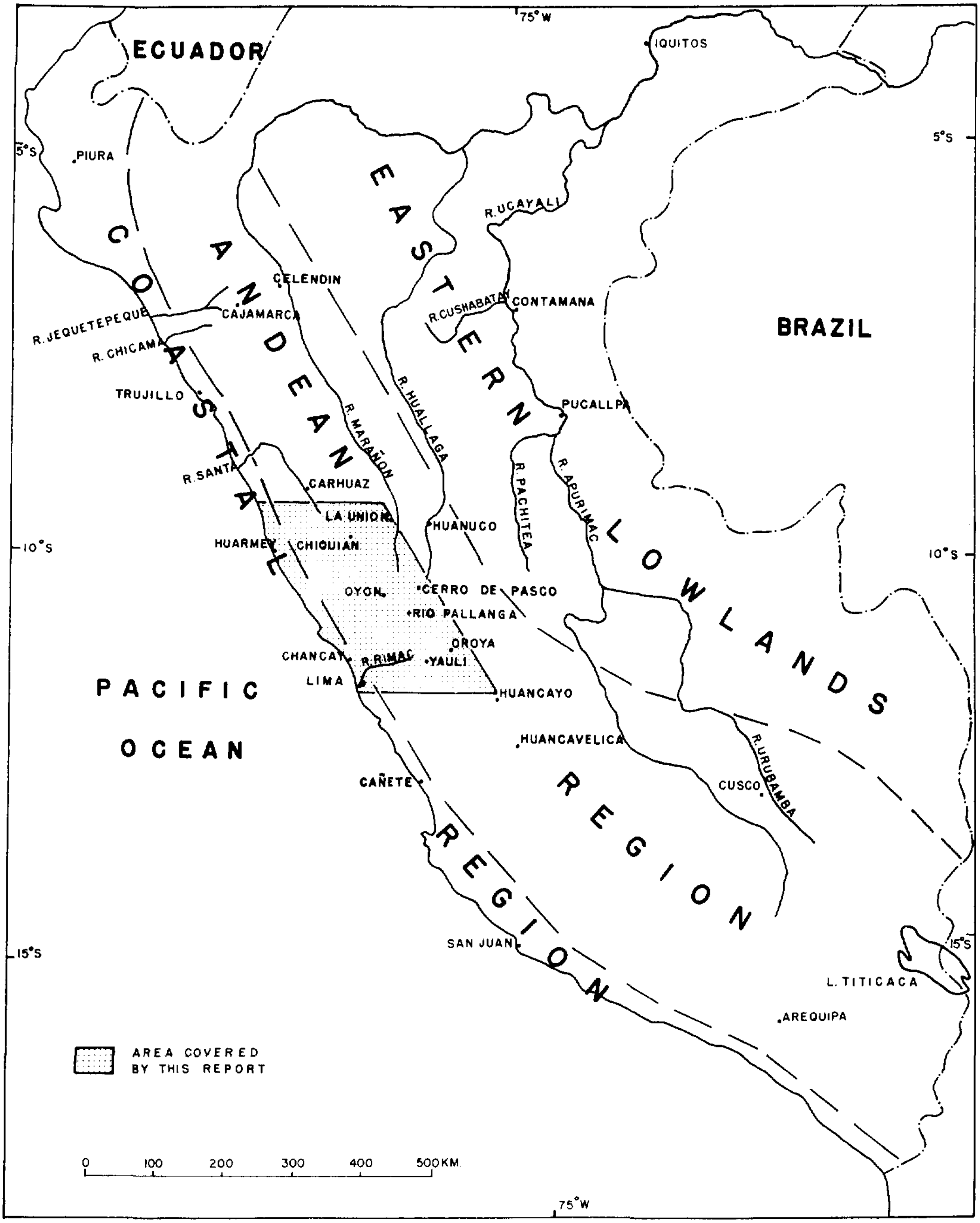


Fig. 1.—Geomorphic provinces of Peru.

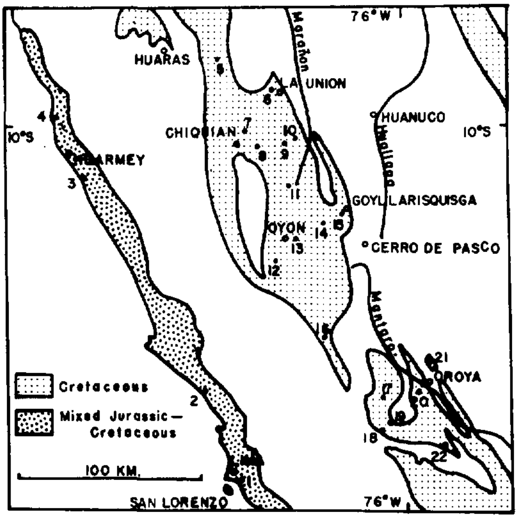


FIG. 2.—Outcrop of Cretaceous System and location of sections in central Peru.

in Figure 2. Each section was measured by means of tape and Brunton.

Structural Geology

Field work and a study of the available literature indicate that the Andean belt in central Peru can be divided into northwest-southeast-trending structural provinces (Fig. 3).

The most southwesterly structural province consists of Paleozoic and Pre-Cambrian massifs which have been described southeast of Lima (Ruegg, 1957) and in northwestern Peru (Fischer, 1956). East of these massifs, and forming the coast of much of central Peru, Mesozoic rocks have been gently folded and block-faulted. Paralleling the coast, and in some places extending to it, is a petrologically complex batholith approximately 30 km. wide. The intrusion has not produced intense deformation and metamorphism in the surrounding rocks, except near the contact.

Between the batholith and the Continental Divide is a belt of strongly folded Cretaceous formations unconformably overlain by Cenozoic volcanics. The Cretaceous formations have been folded into a series of thrust anticlines and synclines, with overturning mainly toward the northeast.

East of the Continental Divide in central Peru lies a belt of strongly folded, metamorphosed, and intruded Paleozoic and Pre-Cambrian rocks which Benavides (1956) named the Marañon geanticline. The western flank of the geanticline is overlain by a relatively thin sequence of Mesozoic and Cenozoic sedimentary formations. Although the sedimentary cover has been folded and locally thrust, structures are less complicated than farther west.

The region east of the Marañon geanticline is underlain by Mesozoic and Cenozoic formations. Little information has been published on the structure of this large area, though it appears to constitute a belt of moderate to gentle folding.

Cretaceous Stratigraphy

Figure 3 illustrates the area of the Peruvian Andes underlain by outcropping Mesozoic formations, the majority of which are Cretaceous. In Northern and Central Peru the Cretaceous outcrop is divided into two major parts by a northwest-southeast-trending belt of pre-Mesozoic rocks (Fig. 3), the Marañon geanticline of Benavides (1956), a positive structure which strongly influenced sedimentation during the Early Cretaceous. Benavides (1956) noted that during the Cretaceous the geanticline was flanked on the northeast and southwest by linear areas of subsidence which are here called respectively the East Peruvian trough and the West Peruvian trough (Fig. 4).

Kummel (1948) described the Cretaceous rocks of the East Peruvian trough as consisting of two formations of continental orthoquartzites and protoquartzites (the Oriente and Vivian Formations) separated by the marine shales and limestones of the Chonta Formation. The formations deposited in the West Peruvian Trough, however, consist of graywackes, shales, and volcanics in the area of coastal Peru, and protoquartzites, orthoquartzites, shales, and carbonates in the Andean Region. The formations lying on the western flank of the geanticline are made up of a lower unit of orthoquartzites and protoquartzites overlain by Albian to Santonian carbonate rocks.

Between Latitudes 7° and 11°45′ South the pre-Albian facies of the West Peruvian trough is quite distinct from that of the Marañon geanticline. West of a line extending from about Rio Pallanga to Celendin the pre-Albian formations are thick and contain marine facies, whereas east of the line the sequence is thinner and does not contain any evidence of marine deposition. In central Peru the change in thickness and lithologic character is so nearly coincidental with the Continental Divide that for practical purposes the divide is regarded

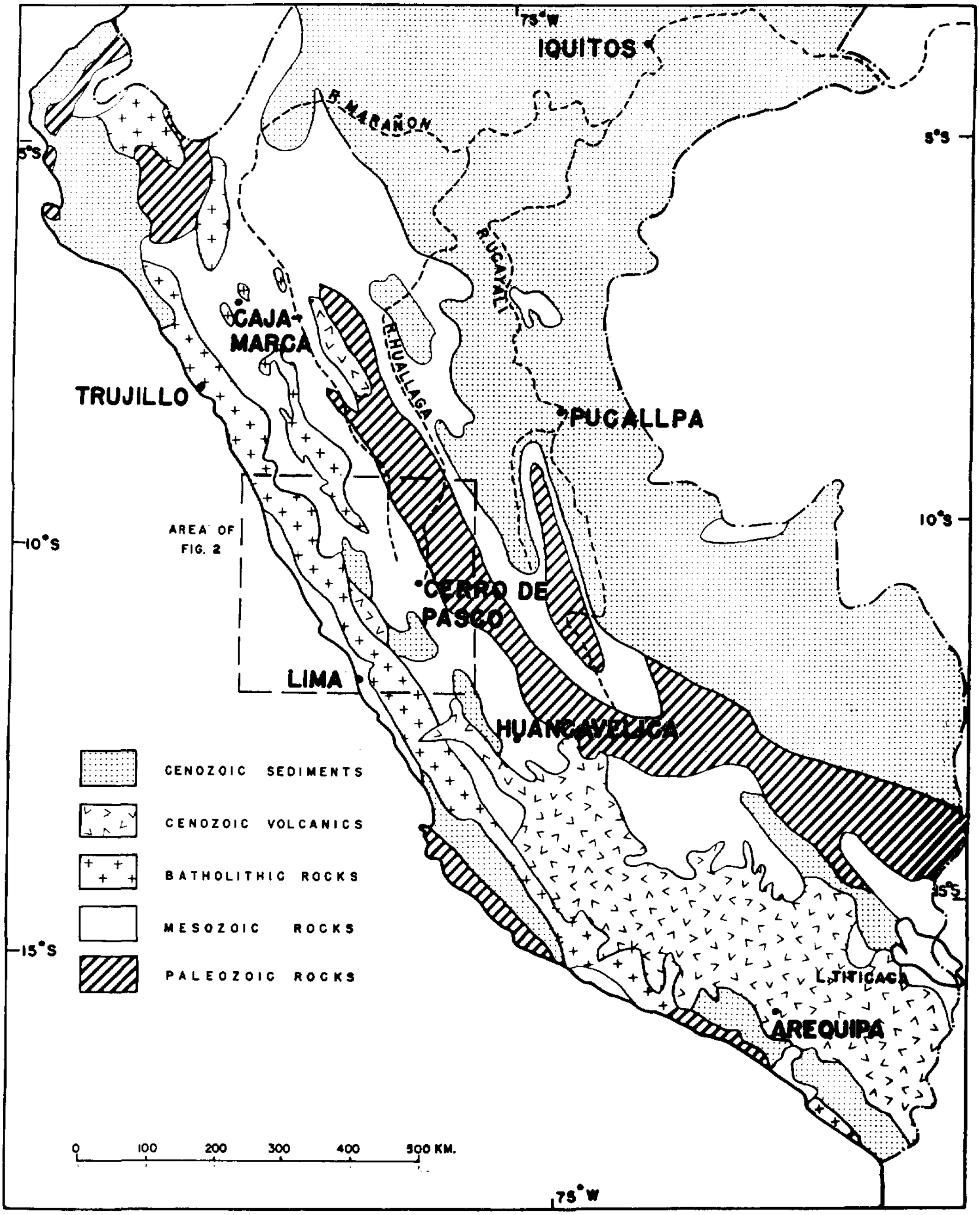


FIG. 3.—Generalized geological map of Peru.

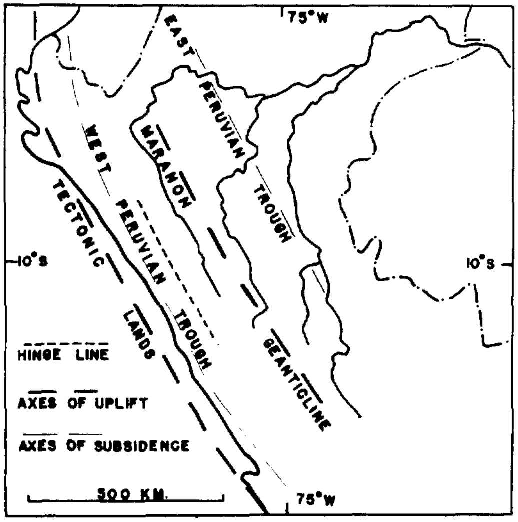


FIG. 4.—Cretaceous tectonic framework of Peru.

as the junction between the two facies.

The Cretaceous rocks which crop out in the area of this report were deposited in the West Peruvian trough and on the flank of the Marañon geanticline. As the outcrop area is divided geographically into a Coastal Region and an Andean Region, this division is maintained in the description of the stratigraphy.

COASTAL REGION

Along the coast of central Peru is a narrow strip of Mesozoic sediments and volcanics about which little is known. Stratigraphic sections were measured at Lima, Chancay, and Huarmey (sections 1–4).

Lima Area

The stratigraphic nomenclature of the Lima section (section 1) officially adopted by the Instituto Geológico del Peru (Rivera, 1951), and used by Rosenzweig (1953) and Fernandez Concha (1958) is tabulated in Figure 8.

The Puente Piedra Formation was described by Rivera (1951) as consisting of approximately 1,900 m. of andesites and water-laid andesitic tuffs with interbedded shales and sandstones. Six hundred meters above the base of the formation is a fossiliferous shale unit 15 m. thick. Rivera (1951) considers the ammonites from this unit to be no older than Late Tithonian and no younger than Berriasian, a conclusion which is in agreement with the zonation of the Argentinian Upper Jurassic and Lower Cretaceous by Leanza (1945, 1947). The Puente Piedra Formation has no known equivalents elsewhere in Peru except in the Huaytara area east of Pisco, where Bellido (1956) found Berriasian ammonites in a shale and sandstone sequence.

The Salta del Fraile Formation, the Herradura Formation, and the Marcavilca Formation constitute a predominantly clastic sequence which is more than 600 m. thick on the island of San Lorenzo (Rosenzweig, 1953) and about 400 m. thick south of Lima (Fernandez Concha, 1958). The Salta del Fraile Formation is light brown, medium-bedded sandstone and is readily distinguished from the intercalated shales, sandstones, and thin limestones of the Herradura Formation. The Marcavilca Formation is thick-bedded, white or gray-colored sandstone.

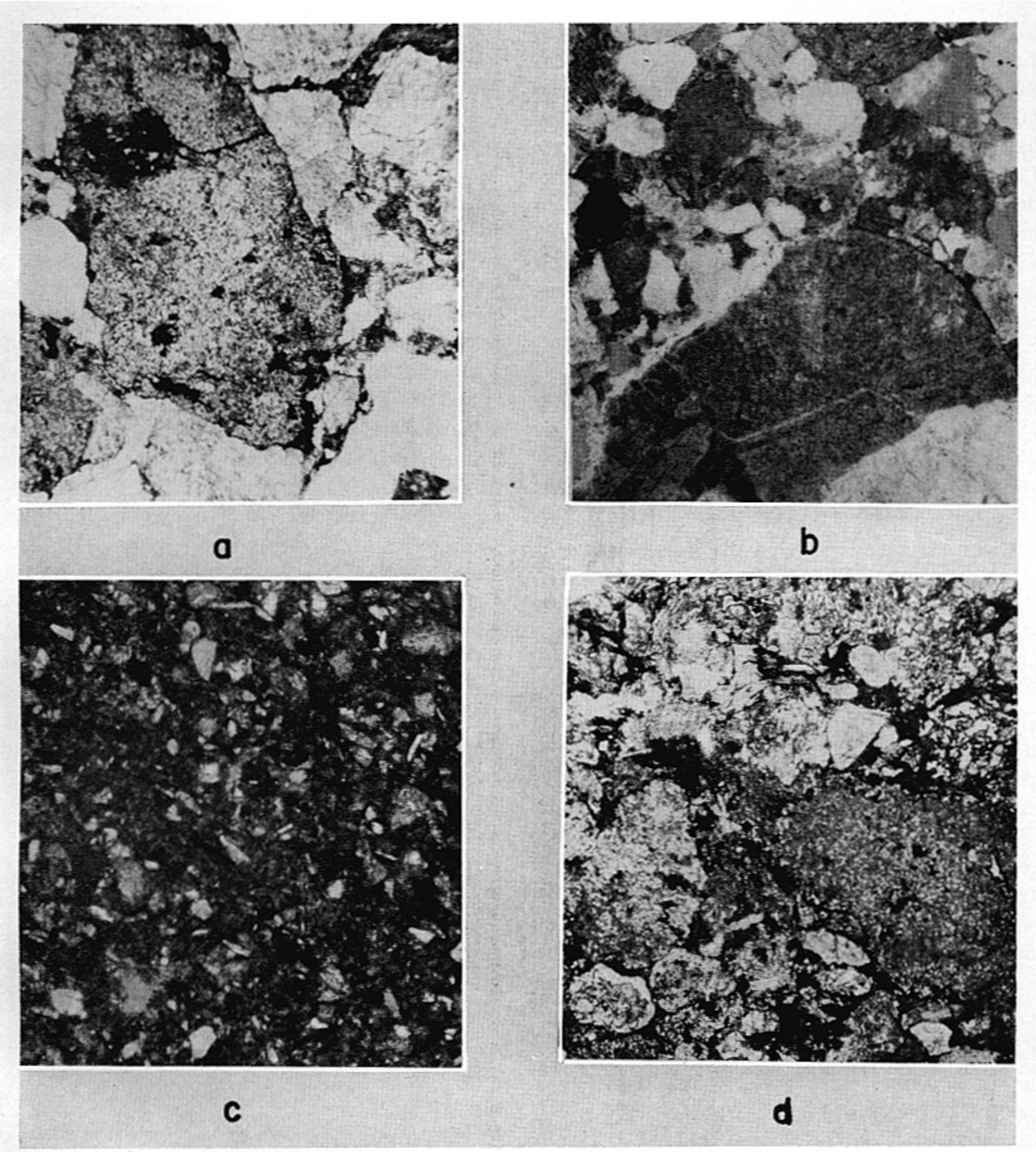
Thin section study of fourteen specimens collected at regular stratigraphic intervals from the aforementioned formations indicates a fairly continuous change in composition from the base of the Salta del Fraile Formation to the top of the Marcavilca Formation. The sandstones of the Salta del Fraile and Herradura Formations are subgraywackes and protoquartzites (Pl. 1a and b). The average of nine estimated modal analyses of these two formations is:

Quartz+Chert	70–75%
Rock fragments	10%
Feldspar	10%
Matrix	5–10%

The rock fragments are, in order of decreasing abundance, quartzite, volcanics, and a quartz-oligoclase type. The feldspar is predominantly plagioclase (average composition An_{30}), though perthite and orthoclase are also present. The sand-size grains are subangular to subrounded, the interstices between them being filled with silty or shaly matrix.

The five thin sections from the Marcavilca Formation are protoquartzites and orthoquartzites consisting of 90 per cent or more of quartz, with minor amounts of rock fragments, feldspar, and matrix. The grains are subrounded, and the interstices are filled with a silica cement.

Cross-bedding of festoon type is common in the sandstones of the Lima area, occurring in units up to a meter thick. Ripple marks are also present. Six measurements of cross-bedding indicate that the sandstones were deposited by a current flowing toward the east-northeast.



PL. 1.—Photomicrographs of Cretaceous rocks of coastal Peru.

a. Subarkose, La Herradura Formation, Lima. Ordinary light, ×30. Consists of quartz (clear), feldspar (clouded), volcanic rock fragments (dark colored), and matrix.

b. Subgraywacke, La Herradura Formation, Lima. Crossed nicols, ×30. Quartz, quartz-oligoclase fragment, andesitic fragments (dark gray), and matrix.

c. Graywacke, unnamed formation, Chancay. Ordinary light, ×30. Angular fragments of quartz, feldspar, and volcanics set in abundant fine-grained matrix.

d. Tuff, unnamed formation, section 4. Ordinary light, ×30. Angular fragments of clear quartz and subangular volcanics set in matrix of small feldspar crystals and fine ash.

The arenaceous formations of the Lima area contain a variety of plant fragments and mollusks. The plant fragments have been considered Late Jurassic by Berry (1922) and other workers, though the ammonites were believed by Lisson (1942, p.76) to indicate a Valanginian age. On the basis of the zonation of the Argentinian section by Leanza (1945, 1947) the Salta del Fraile, Herradura, and Marcavilca Formations are believed to be Valanginian. They are correlative with the Chimu Formation of the Andean Region, and possibly with the Neocomian clastic formations elsewhere in Peru (Fig. 8).

The Pamplona Formation consists of thinly bedded limestones and shales, and contains a molluscan fauna which Lisson (1942) believed indicative of the Late Valanginian or the Hauterivian. The Atocongo Formation is fine-grained, thick-bedded limestone which has not yet yielded diagnostic fossils, though Rivera (1951) suggested a Hauterivian age on the basis that it conformably overlies the Pamplona Formation. Faulting prohibits the measuring of complete sections, and the thickness of the two formations can only be estimated as several hundred meters.

The Puente Piedra Formation is interpreted as a submarine accumulation of lavas and pyroclastics on the basis of the water-laid tuffs and the presence of interbedded marine shales. The flora and fauna found in the Lower Cretaceous sandstones indicate deposition under alternately terrestrial and shallow marine conditions. The terrestrial sediments were possibly laid down as deltas which became temporarily submerged during minor marine advances. Precise data on the environments of deposition of the Pamplona and Atocongo Formations are not available, but it appears probable that Steinmann (1929) was correct in interpreting them as shallow marine deposits.

Chancay Area

Approximately 300 m. of interbedded graywackes, shales, and sills, or flows are exposed on the southern flank of the promontory near the town of Chancay (section 2). The upper 100 m. of the sequence is separated from the lower part by a normal fault with which is associated a small basic intrusion. The upper unit consists of medium- and coarse-grained graywacke in beds up to 2 m. thick. Thin dark beds of pyritic shale separate the graywacke beds from one another. The average composition of three graywackes studied in thin section is:

Quartz	55%
Rock fragments	15%
Feldspar	5%
Matrix	25%

Graded bedding is found in some of the graywacke beds. Load structures occurring between the graywackes and shales, and contorted bedding within the graywackes show a general asymmetry toward the east. Two measurements made on a load cast and a slump structure indicate that at the time of deposition there was a slope toward the southeast.

One bed almost at the top of the unit contains ammonite molds, one of which was tentatively identified by the writer as *Lyelliceras* sp. indet. This genus is restricted to the Lower and Middle Albian. It is common in the Middle Albian Pariatambo Formation of the Central and Northern Andes, with which the Chancay sequence is therefore correlated.

The pyritic nature of the shales and the apparent absence of benthonic fauna suggest deposition in a reducing environment. The graywackes are interpreted as turbidity-current deposits on the basis of the graded bedding (Kuenen, 1951). The contorted bedding and the asymmetrical load casts suggest a slope dipping toward the east.

Huarmey Area

Two sections were investigated near Huarmey (sections 3 and 4). Section 3 is on the western side of the Panamerican Highway at Km. 254, south of the town. Section 4 is at Km. 315 north of Huarmey, and consists of two parts lying on either side of the highway.

Section 3 is made up of 700 m. of thin-bedded shales and fine-grained, commonly tuffaceous, graywackes (Pl. 1c). The average composition of the ten graywacke specimens studied in this section is:

Quartz	40%
Volcanic rock fragments	20%
Feldspar	15%
Matrix	25%

Massive beds of agglomerate also occur, made up of fragments of volcanic glass, grains of feldspar, and shaly rock fragments. The fragments of volcanic glass are angular, and contain laths of feldspar showing parallel extinction. Weathering

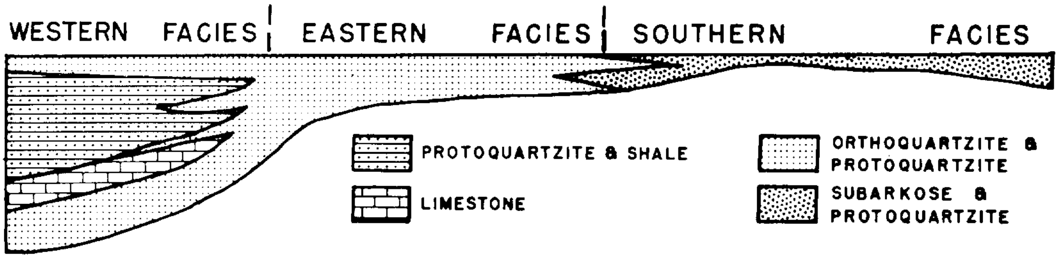


FIG. 5.—Lithological relationships between facies of Goyllarisquisga Group.

prevents the recognition of many of the grains of feldspar in thin section studies, though oligoclase and andesine appear to be common types.

At section 4, north of Huarmey, the sequence is interrupted by folding and faulting. A lower unit, 690 m. thick, lies east of the road; the upper unit, 896 m. thick, is situated west of the road. The stratigraphic gap between the two units is estimated at about 100 m.

Of the 21 thin sections studied from section 4, 8 are graywacke, 5 are tuffs, 4 are volcanic flows or sills, 2 are agglomerates, and 2 are limestones.

The graywackes have an estimated average composition of:

Quartz	20%
Rock fragments	20%
Feldspar	30%
Matrix	30%

The rock fragments consist of approximately equal proportions of andesite and metaquartzite. About half of the feldspar is orthoclase, the remainder being sodic plagioclase with an average composition of An_{20}. The agglomerate and tuff include both vitric and lithic types, and have an average composition close to that of andesite (Pl. 1c). Varying amounts of calcium carbonate are present in the tuffs, one of which approaches a tuffaceous limestone in composition. The flows or sills are pyroxene andesites and basalts. The limestones occur as thin discontinuous bands, and are fine-grained, non-fossiliferous, and silty.

The rocks of sections 3 and 4 do not contain a great variety of sedimentary structures, though examples of graded bedding were seen. Slump structures also occur, though exposures were too poor to permit an accurate determination of the direction of sediment transport.

No fossils were found at sections 3 and 4. On the basis of an hoplitid ammonite found in the Huarmey area by Broggi (Lisson, 1942, p. 71) the sequence is provisionally regarded as Cretaceous in this report.

The graywackes and tuffs of sections 3 and 4 are interpreted as deposits laid down in a region of active volcanicity. Large quantities of tuffaceous material were explosively erupted, and submarine lava flows also took place. The graded bedding seen in the graywackes suggests that at least part of the material was transported by turbidity currents.

ANDEAN REGION

Goyllarisquisga Group

The pre-Albian clastic sequence east of the Continental Divide in central Peru was called by McLaughlin (1924) the Goyllarisquisga-Jatunhuasi sandstone, though Jenks (1951) changed the name to the Goyllarisquisga Formation. West of the Continental Divide, and separated from the type area by a belt of Albian and Upper Cretaceous carbonate rocks, is a thicker and more varied sequence of largely clastic pre-Albian rocks. It is proposed that the term Goyllarisquisga Group be adopted to refer to all the Cretaceous rocks underlying the Albian limestones in the Central and Northern Andes. No divisions of the group are made in the eastern outcrop area. On the west, however, the following formations are recognized in ascending order: Oyon Formation, Chimu Formation, Santa Formation, Carhuaz Formation, and Farrat Formation (Fig. 8).

The Goyllarisquisga Group can be divided into three facies, the lithologic characters and relative thicknesses of which are shown diagrammatically in Figure 5. The western facies, which is a thick sequence of sandstones, shales, and some limestones, lies west of the Continental Divide, and extends from Canta northwestward into the Northern Andes. The eastern facies is a sequence of orthoquartzites mainly east of the Continental

Divide, and stretches for several hundred kilometers northwestward from Cerro de Pasco. The Goyllarisquisga Group southeast of Rio Pallanga differs in thickness and lithologic character from both the eastern and western facies, and is here referred to as the southern facies. The facies may extend as far south as Huancvelica, where Fernandez Concha (1952) reported a sequence similar to that of section 22.

SOUTHERN FACIES

The Goyllarisquisga Group is represented by a variable thickness of sandstones and shales at sections 17–22. The group is more than 800 m. thick at section 22, but averages only 200 m. at the other sections.

Field observations indicate that the southern facies of the group may be divided into two units which are of more or less equal thickness at any one section. The lower unit is a sequence of pink or purple sandstones, conglomerates, and gray limestone, whereas the upper unit consists of white or yellowish weathering sandstones which commonly contain coaly layers.

Thin-section studies of the lower unit show it to be a moderately well sorted subarkose. The average modal analysis of fourteen specimens is:

Quartz+chert	>80%
Feldspar	<10%
Rock fragments	< 5%
Matrix	> 5%

The feldspar is mostly plagioclase (average composition An_{30}), with minor amounts of orthoclase, microcline, and perthite. The majority of rock fragments are metaquartzite grains, though volcanic fragments also occur.

Thin-bedded limestones are found within the lower unit at sections 17, 18, and 22. The limestones contain shell fragments, but no identifiable remains were found.

The upper unit of the southern facies of the Goyllarisquisga Group is a sequence of orthoquartzites and protoquartzites. The eight thin sections of this unit which were studied gave an estimated average composition of:

Quartz	>90%
Rock fragments	< 5%
Matrix	5%

Feldspar is present in small amounts, but is not quantitatively important.

Cross-bedding of the festoon type is abundantly exhibited in the sandstones of this facies, and ripple marks are also present. Slump structures were found at several horizons in the subarkose unit of section 22.

Twenty-eight measurements of slump structures and cross-bedding were made in the areas of sections 17–22. The seven measurements made at sections 20 and 21 indicate a current direction toward the west. The remaining measurements made at sections 17, 18, 19, and 22 indicate an average current flow toward the east and northeast.

The only fossils found to date in the southern facies of the Goyllarisquisga Group are plant fragments, collected from dark shales. Berry (1922) found *Thuites leptocladoides* Berry and *Equisetites* sp. indet. at Jatunhuasi, near section 22. These fossils are inadequate for dating the strata within which they lie, as different workers place them in the Upper Jurassic or Lower Cretaceous. The majority of workers believe that the flora has Neocomian affinities. Fernandez Concha (1952) mentioned finding corals in limestone beds within the Lower Cretaceous sandstones of Huancavelica. Study of this material may facilitate the precise dating and correlation of this facies.

The anomalous sequence at section 21 poses a problem. Whereas at sections 17–20 the Lower Cretaceous lies directly on the Lower Jurassic-Upper Triassic limestones, at section 21 the Goyllarisquisga Group disconformably overlies a 300-m. sequence of conglomerates and arkoses, which are in turn disconformably underlain by Lower Jurassic. Of what age are the sub-Goyllarisquisga clastics, as they are called in this report? Are they merely a basal unit of the Goyllarisquisga Group, or are they appreciably older?

The Goyllarisquisga Group is very uniform in this region, as shown by the similarity in thickness and lithological characteristics between sections 20 and 21. In none of the surrounding sections, 17–20, is there evidence of considerable relief on the sub-Goyllarisquisga surface. It is therefore unlikely that the sub-Goyllarisquisga clastics represent the infilling of a basin by a basal unit of the Goyllarisquisga Group. The writer believes that the arkoses and conglomerates of section 21 may represent a unit appreciably older than the Goyllarisquisga Group itself. This belief is supported by the observation that the sub-Goyllarisquisga clastics are cross-bedded from the west whereas the Goyllarisquisga Group was derived from the northeast and east. This difference in source area indicates paleogeographic changes of some magnitude, which in turn suggests the passage of a not inconsiderable period of time.

From this above discussion it can be concluded that although the sub-Goyllarisquisga clastics may be a basal unit of the Goyllarisquisga Group, the evidence at present available suggests that they are considerably older. As they overlie the Lower Jurassic and underlie the Lower Cretaceous they must represent a part of the Middle or Upper Jurassic. Whereas the Middle Jurassic is poorly developed in Peru, Upper Jurassic clastics are relatively common. On this basis the sub-Goyllarisquisga clastics are provisionally regarded as Upper Jurassic.

We are therefore faced with the possibility that the Upper Triassic-Lower Jurassic limestones were at one time covered by a clastic formation which was largely eroded before the deposition of the Lower Cretaceous Goyllarisquisga Group. This is a point which should be borne in mind by field geologists working in the Peruvian Andes, where it has previously been the custom to consider as Lower Cretaceous any clastics overlying the Lower Jurassic limestones.

On the basis of the coal seams, the sedimentary structures in the sandstones, and the presence of limestone beds, the southern facies of the Goyllarisquisga Group is interpreted as a mixed deltaic and shallow marine sequence. The poorly sorted and immature sandstones in the lower part of the facies suggest rather rapid accumulation, whereas the orthoquartzites at the top of the sequence indicate a considerable amount of weathering and winnowing prior to deposition.

EASTERN FACIES

The eastern facies of the Goyllarisquisga Group is a sequence of orthoquartzites with a fairly uniform thickness of 500–600 m. at sections 6, 9, 10, 11, 14, and 15.

The seventeen thin sections studied from this facies are orthoquartzites containing more than 95 per cent of subrounded and rounded quartz grains. Feldspar, rock fragments, and matrix usually constitute less than 5 per cent of the rock. Heavy minerals are rare, and consist of rounded grains of zircon and tourmaline. The median size of the quartz grains is estimated at approximately 0.5 mm. In almost all places the rock has been indurated with a silica cement, giving a hard, dense quartzite (Pl. 2b).

Thin beds of carbonaceous shale and coaly layers are interbedded with the sandstones, but rarely make up more than 1 or 2 per cent of this facies. Poorly sorted beds of gravel and conglomerate are not uncommon.

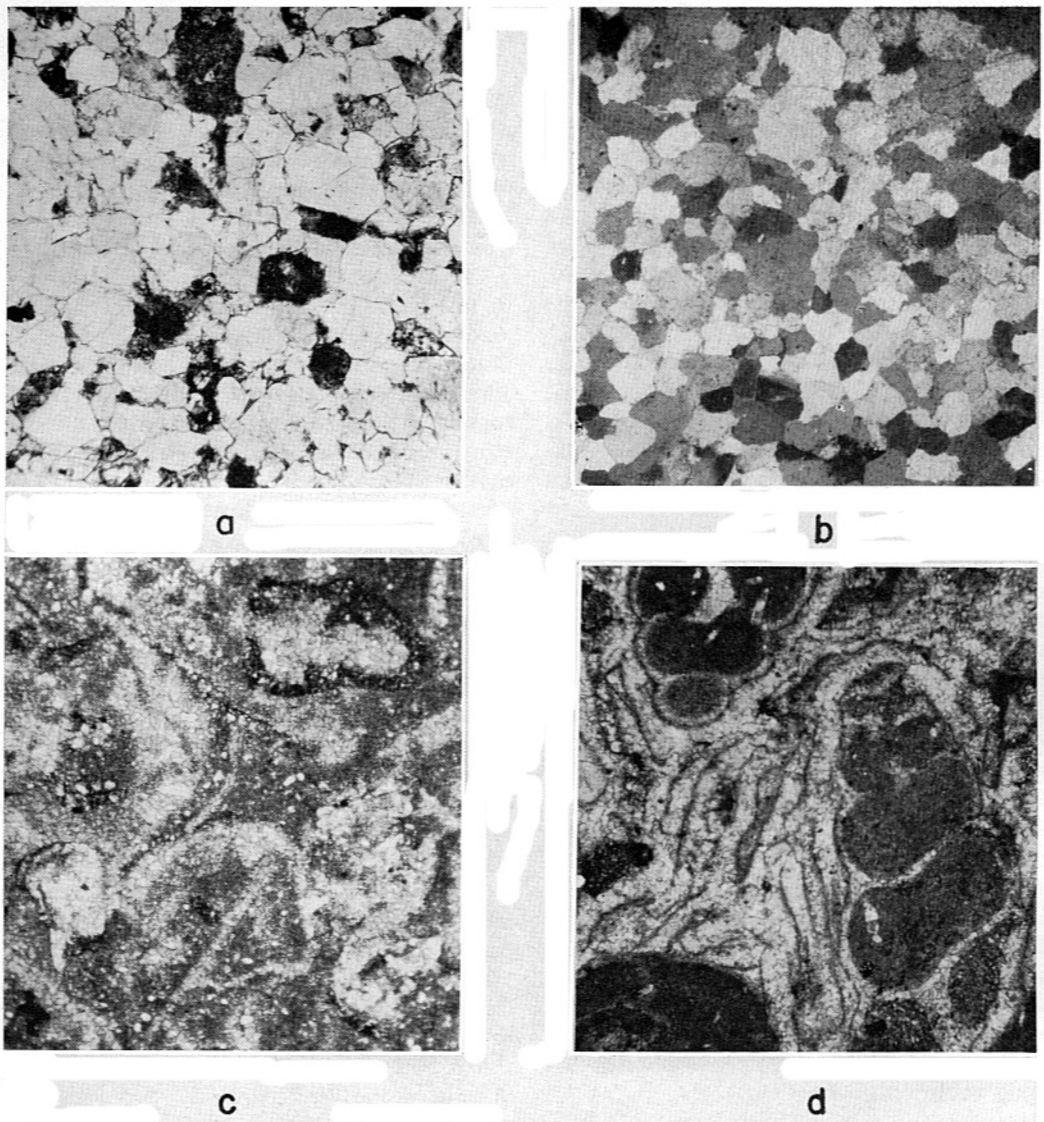
The sandstone units are cross-bedded in units up to 2 meters thick. It is estimated that approximately two-thirds of the cross-bedding is of the festoon type, the remainder being torrential. Ripple marks are also common. The average of thirteen measurements of directional sedimentary structures (sections 6, 10, 11, 15) indicates a current flow toward the west-southwest. This is supported by numerous estimates of cross-bedding directions which were made without correcting for the dip of the beds.

Brachyphyllum pompeckji Salfeld and *Otozamites neumanni* Zeiler were collected from shales at Goyllarisquisga. These plants are inadequate for precise dating. The facies is provisionally regarded as Neocomian to Lower Albian on the basis that it is overlain by the Middle Albian. It is therefore correlative with much of the Oriente Formation in eastern Peru (Kummel, 1948), and with the Murco Formation of the Arequipa area (Jenks, 1948).

The plant-bearing shales and coaly layers which are found at numerous horizons in the sequence, coupled with the complete absence of marine invertebrates, suggest that this facies of the Goyllarisquisga Group is of terrestrial origin. Moderate or high current velocities are inferred from the pebble bands. The facies was probably deposited in deltas or in river floodplains.

WESTERN FACIES

The western facies of the Goyllarisquisga Group is considerably thicker and lithologically more varied than its eastern equivalent. The group is more than 1,500 m. thick at section 8, and at Carhuaz, 100 km. northwest, the Lower Cretaceous clastics are about 2,000 m. thick (Benavides, 1956). Although the western facies of the Goyllarisquisga Group contains white quartz sandstones of the type which characterize the eastern facies, it includes a much higher proportion of shales and siltstones. Limestones are



PL. 2.—Photomicrographs of rocks of Goyllarisquisga Group, Chulec Formation, and Jumasha Formation.
a. Subarkose, Goyllarisquisga Group, southern facies, section 22. Ordinary light, ×30. Quartz (clear), commonly with overgrowths, and weathered feldspar.
b. Orthoquartzite, Goyllarisquisga Group, eastern facies, section 15. Crossed nicols, ×15. Rounded grains of quartz held together by silica cement.
c. Fossil fragmental limestone, Chulec Formation, section 6. Ordinary light, ×30. Recrystallized fragments of shell material set in matrix of granular calcite and silt.
d. Fossil fragmental dolomite, Jumasha Formation, section 15. Ordinary light, ×30. Recrystallized fragments of macrofossils and foraminifera, in a matrix of medium-grained dolomite.

present both in the Santa Formation and the Carhuaz Formation.

Oyon Formation.—This formational name is proposed for the unit referred to by Harrison as the Lower Cretaceous Coal Measures. The type section is in the thrust anticline directly west of the town of Oyon, where the formation is represented by approximately 100 m. of thinly bedded subgraywackes, shales, and lenticular coal seams. The formation is not present outside of the Central Andes, and is nowhere seen in its entirety within the region. From north to south it is exposed at sections 5, 6, 13, and 16. It does not occur east of the Continental Divide, where quartz sandstones lie directly on the limestones of of the Pucará Formation.

Although the base of the formation is not seen, because of structural complexities, the upper limit is well defined by the change from the thin-bedded sandstones and shales of the Oyon Formation to the thick-bedded sandstones of the Chimu Formation.

The writer did not find any identifiable plant fragments in the Oyon Formation, but Berry (1922) reported *Otozamites goeppertianus* (Dunkeld) and *Weichselia* cf. *mantelli* (Dunkeld) from the type section. Lisson (1942) considered this flora indicative of the Neocomian, though Berry (1922) believed that a Jurassic age was possible. The oldest dated horizon in the Andean Cretaceous, the Upper Valanginian Santa Formation, lies about 600 m. stratigraphically above the Oyon Formation, whose age is therefore probably Early Valanginian or Berriasian. A Tithonian age can not, however, be completely ruled out. Although precise correlation is not yet possible, the Oyon Formation is probably equivalent to the lower parts of both the sandstone sequence at Lima and the Murco Formation in the Arequipa area (Jenks, 1948).

The fine-grained, but rather poorly sorted nature of the rocks suggests a weak current system. This factor, together with the presence of coal seams, suggests that the Oyon Formation may have been deposited in a system of swamps.

The Oyon Formation is an important horizon in Andean tectonics. During the Andean orogeny this formation acted as a plane of weakness along which movements commonly occurred. Where present, it is associated with complex structures, a common type being the thrusting of the Chimu Formation over younger rocks, with the Oyon Formation acting as a lubricant. East of the Continental Divide, where the Oyon Formation is missing, structures are more open and thrusting is less common. Although geological mapping is not yet adequate to justify a final statement, it seems that the area underlain by the Oyon Formation forms a structural unit in which décollement along this weak horizon is the principal type of deformation.

Chimu Formation.—Benavides (1956) defined the Chimu Formation at Baños de Chimu in the Chicama Valley of northern Peru as 685 m. of quartz sandstones with intercalated shales and coal. It is disconformably underlain by the shales of the Tithonian Chicama Formation, and conformably overlain by the limestones and shales of the Santa Formation. In the Central Andes a 500–700-m. sequence of metaquartzites is correlated with the Chimu Formation on the basis of its similar lithologic character and stratigraphic position beneath the Santa Formation.

The Chimu Formation has a fairly constant thickness and lithologic character over the whole of its outcrop area, which extends between Latitudes 7°30′ and 11°45′ South. It usually maintains a thickness of between 500 and 700 m. The study of ten thin sections shows the formation to be predominantly an orthoquartzite consisting of well rounded quartz grains held together by a silica cement. Rock fragments are rare, and are restricted to rounded particles of metaquartzite. Feldspar is absent, and matrix nowhere makes up more than 5 per cent of the rock. Only two or three grains of heavy minerals are seen in any one thin section, the assemblage consisting of zircon, tourmaline, and titanite. From the foregoing it can be seen that the formation strongly resembles the eastern facies of the Goyllarisquisga Group.

The mean grain size for the formation is estimated as a medium sand though conglomeratic and silty bands are not unknown. Black carbonaceous shales, locally associated with anthracite, are found interbedded with the orthoquartzites.

The sandstones of the Chimu Formation are medium- to thick-bedded. Cross-bedding of both festoon and torrential type is common. Ripple marks are also abundant, though slump structures were seen only in the area of section 7. Eleven measurements of cross-bedding and slump structures give an average direction of sediment transport toward the southwest. Numerous estimates made without allowing for the dip of the beds confirm this direction.

The only fossils found in the Chimu Formation are plant fragments. On the basis of the probably Late Valanginian age of the Santa Formation, the Chimu Formation is placed in the Valanginian. It is therefore correlative with the sandstone formations of the Lima area, and possibly with the Lower Cretaceous sandstones of eastern Peru (Kummel, 1948).

The Chimu Formation is similar to the eastern facies of the Goyllarisquisga Group in lithologic character, sedimentary structures, and fossil content. It is therefore believed to have been deposited in the same sedimentary environment of deltas and floodplains.

Santa Formation.—The Santa Formation was defined by Benavides (1956) for 341 m. of limestones and shales which crop out 6 km. northwest of Carhuaz. A similar unit occurs in the Central Andes. It is well exposed in the Chiquian area (section 8), where it consists of 14 m. of shales and thin-bedded sandstones overlain by 139 m. of medium-bedded limestones, shales, and dolomites. This unit is correlated with the Santa Formation on the basis of lithologic similarity and stratigraphic position. The formation is also present at sections 5, 7, 8, 12, 13, and 16.

Section 8 is the only section visited in which both the upper and lower contacts of the Santa Formation can be clearly observed. The lower contact, which is placed at the top of the medium-bedded quartzites of the Chimu Formation, is conformable. The upper contact is placed at the top of the limestone sequence, above which lie the sandstones of the Carhuaz Formation.

The basal unit of the Santa Formation consists of up to 50 m. of cross-bedded sandstones and shales containing small plant fragments. The carbonates of the upper unit of the formation commonly consist of comminuted shell debris set in a fine-grained calcium carbonate matrix. Silicified oölitic limestones, some of which show ripple marking, are present, but do not constitute more than 5 per cent of the formation at any one of the sections visited. Beds of rusty weathering dolomite up to 1 m. thick occur in some of the sections.

Benavides found *Valanginites broggii* (Lisson) in the Santa Formation of northern Peru, and considered it probably indicative of the Late Valanginian. The formation did not yield any diagnostic fossils in central Peru, but is probably the same age as in northern Peru. It is therefore correlative with the Pamplona Formation of the Lima area, and probably has equivalents in the Lower Cretaceous sandstone formations of other parts of the Andes.

The ripple marks, sporadically distributed oölitic beds, and the absence of pelagic invertebrates suggest deposition in a near-shore environment. This interpretation is supported by the abundance of bioclastic material in the formation.

Carhuaz Formation.—Benavides (1956) defined the Carhuaz Formation for 1,554 m. of sandstones and shales exposed in the Santa valley. The formation crops out extensively on the western flank of the Peruvian Andes, but does not extend east of the Continental Divide in central Peru.

The lower contact of the formation is conformable at all the sections visited. Fossiliferous sandstones and shales at the base of the formation grade downward into the limestones of the Santa Formation. At the type section the top unit of the formation is medium-bedded orthoquartzite and protoquartzite. The writer considers this unit to be the lateral equivalent of a thick metaquartzite unit found at this horizon in the Northern Andes, and named the Farrat Quartzite by Stappenbeck (1929). Benavides (1956) correlated the Farrat Quartzite of the Northern Andes with the Central Andean Goyllarisquisga Formation of Jenks (1951). However, the Farrat Quartzite is equivalent to only part of the Goyllarisquisga Formation of Jenks (1951), and should be named the Farrat Formation to avoid ambiguity. In this report the medium-bedded sandstones at the top of the Carhuaz Formation of Benavides (1956) are regarded as equivalent to the Farrat Formation, and are named accordingly. The upper contact of the Carhuaz Formation as here defined is gradational at most sections, and is drawn where medium-bedded sandstones begin to constitute more than 50 per cent of the sequence.

The Carhuaz Formation is predominantly a clastic sequence consisting of thin- to medium-bedded sandstones, siltstones, and shales which weather to browns, yellows, and reds. At the top of the formation is a variegated siltstone unit. The sandstones of the Carhuaz Formation are poorly sorted protoquartzites. Dark shales, commonly associated with coaly layers, make up from a quarter to a half of the formation, the proportion increasing toward the west. Thin beds of limestone occur, and they too are most common in the west.

The sandstones and siltstones of the Carhuaz Formation contain a variety of sedimentary structures. Small-scale cross-bedding and current ripple marks are common. Examples of flow casts are seen on the soles of some of the sandstone beds.

Poor exposures and the small scale of the cross-bedding prevent accurate measurements in many places. The nine observations which were made indicate an average current direction toward the west.

The dark shales of the Carhuaz Formation contain molds and casts of pelecypods and gastropods. The writer has identified the gastropod as *Paraglauconia* cf. *studeri*, which also occurs in the type section. *Cyrena huarazensis* Fritzsche is also common.

No ammonites were found in the Carhuaz Formation. The age range can, however, be obtained from the fact that the underlying Santa Formation is Late Valanginian, whereas the first diagnostic fossils above the formation are Early Albian. The Carhuaz Formation is therefore Early Hauterivian to Aptian in age.

Stratigraphic relations suggest that the formation is correlative with the eastern facies of the Goyllarisquisga Group. It is equivalent to part of the Oriente Formation of eastern Peru, where Kummel (1948) found Aptian fossils in the Esperanza Member. The Carhuaz Formation is also correlated with the Murco Formation of Arequipa (Jenks, 1948) on the basis of similar lithological characteristics and stratigraphic position. The Huancané Formation of the Titicaca area (Newell, 1949) is probably a partial equivalent.

Both *Paraglauconia* and *Cyrena* are characteristic of brackish-water deposits. As plants and coaly layers are also common it seems that the environment of deposition was a widespread system of coastal swamps. The beds of oölitic limestone indicate the sporadic development of shallow marine conditions.

Farrat Formation.—Although the Farrat Formation of the Northern Andes is several hundred meters thick, it is represented in the Central Andes by only a few tens of meters of sandstones which lie conformably on variegated siltstones of the Carhuaz Formation. At section 7, however, the formation appears to be separated from the Carhuaz Formation by an angular unconformity of about 5°. The upper contact is drawn where the quartz sandstones become brownish and calcareous, indicating the base of the Pariahuanca Formation.

The maximum thickness of the formation in central Peru, measured at section 7, is 80 m. The average thickness for the region is about 40 m. The formation consists of medium- to coarse-grained, moderately to poorly sorted protoquartzites and orthoquartzites. The average composition of the sandstones was estimated from the study of ten thin sections as:

Quartz	90%
Rock fragments	< 5%
Matrix	> 5%

Although sedimentary structures are not common in the Farrat Formation, four observations of festoon-type cross-bedding were made. These measurements indicate an average current direction toward the southwest.

No fossils were found in the Farrat Formation, but its stratigraphic position beneath the Lower Albian Pariahuanca Formation suggests that it is Late Aptian in age. It is correlated with the upper part of the eastern facies of the Goyllarisquisga Group on the basis of lithology and stratigraphic position. The formation is also correlated with the Agua Caliente Member of eastern Peru (Kummel, 1948), for the reason that both units are regressive sandstones overlying brackish-water and marine beds of known Aptian age.

The Farrat Formation is interpreted as a regressive sandstone unit deposited when deltaic or fluviatile conditions spread into the West Peruvian Trough at the end of the Aptian.

Pariahuanca Formation.—Lying above the Farrat Formation are several tens of meters of medium-bedded limestones and calcareous sandstones which are correlated with the Pariahuanca Formation of Benavides (1956). The lower part of the formation consists of calcareous sandstones which are distinguished from the sandstones of the Farrat Formation by their calcareous content, greater tendency to be eroded, and the fact that they weather yellowish brown rather than white or gray. The upper limit of the formation is placed where the medium-bedded limestones pass into the thin-bedded marls, calcareous sandstones, and limestones of the Chulec Formation.

The Pariahuanca Formation has a maximum thickness in the Central Andes of Peru at section 16, northeast of Canta, where it is represented by 210 m. of medium-bedded gray limestone with a few intercalations of dolomite, shale, and sandstone. The formation wedges out eastward, and does not occur east of the Continental Divide. The thinning process is well displayed in the Oyon area by sections 12 and 13, where the formation is respectively 120 m. and 54 m. thick.

The limestones which make up the bulk of the formation consist of shell material set in a matrix of fine-grained calcium carbonate. Some beds are virtual shell banks, with gastropods and *Exogyra* occurring in profusion. Many of the shells are whole, though fragmental material is also common. Except at the base of the formation, terrigenous clastics do not occur in significant quantities. Oölites are not commonly found in the formation.

The Pariahuanca Formation is fossiliferous, containing numerous poorly preserved specimens of a limited number of species. The most common fossil is a large *Exogyra* sp. indet. Specimens of *Nerinea* with delicately tapered spires up to 15 cm. tall are also abundant. A *Natica* sp. indet. is common in some beds, and rudistid fragments also occur. Part of the mold of a large cephalopod, possibly *Parahoplites*, was found at section 8, east of Chiquian.

Benavides reported a single ammonite, *Parahoplites*, from the type section of the Pariahuanca Formation and believed it to represent an Early Albian age. Fritzsche (1924) and Steinmann (1929) considered the rudistid fauna to be Barremian. The material collected by the writer is inadequate for the solution of the problem, but the presence of the lower Middle Albian Chulec Formation conformably above the Pariahuanca Formation suggests an Early Albian age for the latter.

As the Inca Formation of the Northern Andes contains *Parahoplites* and lies in the same stratigraphic position as the Pariahuanca Formation (Benavides, 1956), the two formations are believed to be time equivalents. The top beds of the eastern facies of the Goyllarisquisga Group are correlated with the Pariahuanca Formation on the basis that they both lie conformably beneath the Chulec Formation. The Aptian-Albian Arcurquina Formation of the Arequipa area (Jenks, 1948) also contains Pariahuanca equivalents. In eastern Peru the oldest beds of the Huaya Member are Albian in age (Kummel, 1948), and may be correlative with the Pariahuanca Formation. Where the basal Huaya is younger than Albian, the Pariahuanca equivalent lies in the Agua Caliente Member.

The fauna of the Pariahuanca Formation, particularly the rudistids, implies deposition in a shallow sea. The extreme rarity of pelagic invertebrates in the formation suggests a near-shore environment. The basal calcareous sandstones of the formation may be a littoral facies on the basis that they are overlain by fully marine limestones and underlain by the terrestrial Farrat Formation.

Chulec Formation.—This unit was first described by McLaughlin (1924) as the lower member of his Machay Formation. In 1956 Benavides raised the Chulec to the rank of formation, a practice which is followed in this report.

The formation consists of 100–200 m. of marl, limestone, and calcareous sandstone. It can be divided into two units, the upper being made up of thin-bedded limestones and marls, and the lower of calcareous sandstones and marls. The ratio of the lower unit to the upper unit decreases eastward.

The Chulec Formation is underlain in the west by the limestones of the Pariahuanca Formation and in the east by the quartz sandstones of the Goyllarisquisga Group. The lower contact of the Chulec Formation appears conformable, though gravel banks at the top of the Goyllarisquisga Group at section 15 and the presence of coal seams at the Chulec-Goyllarisquisga contact at section 22 may indicate disconformity. In the west the base of the formation is taken as the horizon at which the first marls appear above the Pariahuanca Formation. In the east the base is regarded as the first calcareous and fossiliferous horizon above the sandstones of the Goyllarisquisga Group. The upper limit of the formation is placed where the limestones and marls become bituminous.

In the southern part of the Central Andes a massive, light gray, coquinoid limestone up to 8 m. thick forms the topmost unit of the Chulec Formation, and is overlain by the dark-colored, thinly bedded shales and limestones of the Pariatambo Formation.

Eight thin sections were made to study the nature of the calcareous sandstones and the limestones. The former consist of subangular to subrounded quartz grains more or less surrounded by calcareous cement. The limestones contain abundant shell fragments (Pl. 2c), and are commonly dolomitic. Oölitic and silty limestones also occur.

The faunal list for the formation is as follows.[3]

[3] The significance of the symbols used in this and succeeding faunal lists is:
· Found only in the Central Andes (this report).
·· Found only in the Northern Andes (Benavides, 1956).
No period. Found in both the Central and Northern Andes.

CEPHALOPODA

Protanisoceras blancheti (Pictet and Campiche)*
Douvilleiceras monile (Sowerby)
Parengonoceras pernodosum (Sommermeier)
Parengonoceras tetranodosum (Lisson)
Parengonoceras haasi Benavides*
Knemiceras raimondii Lisson
Knemiceras attenuatum Hyatt
Knemiceras syriacum (von Buch)
Knemiceras gabbi Hyatt
Knemiceras triangulare Benavides*
Knemiceras ovale Benavides*
Knemiceras ziczag Breistroffer
Brancoceras aegoceratoides Steinmann
Lyelliceras lyelli (Leymerie)

PELECYPODA

Cucullea brevis Gerhardt
Cucullea gerhardti Olsson
Modiolus mutissus Olsson
Neithea morrisi Pictet and Renevier
Exogyra aquila Brogniart
Exogyra boussingaulti d'Orbigny
Myopholas peruviana Olsson
Yaadia hondaana (Lea)
Buchotrigonia abrupta (von Buch)
Pterotrigonia tocaimaana (Lea)
Cardita subparallela Gerhardt
Astarte debilidens Gerhardt
Protocardium elongatum Gerhardt
Nucula turgida Olsson
Pinna sp. indet.**
Modiola pongena Olsson**
Pecten cf. *tenouklensis* Coquand**
Pecten cf. *sieversi* Steinmann**

GASTROPODA

Turritella peruvianum Gabb**

ECHINOIDEA

Enallaster peruanus Gabb
Holectypus (*Coenholectypus*) *planatus numismalis* Gabb
Phymosoma texanum Roemer
Echinobrissus subquadratus d'Orbigny
Bothriopygus compressus Gabb

The relative abundance of the foregoing genera varies within a section and from section to section, a variation that is related to the rock type. The lower, more clastic, facies of the formation is characterized by the following fossils in order of decreasing abundance: *E. minos*, *N. quinquecostata*, *H. planatus*, and many bivalves. The upper, more calcareous, facies of the formation has fewer specimens of *E. minos* and *H. planatus*, but contains ammonites and gastropods in large numbers.

Although most early workers considered the Chulec Formation Aptian in age, the presence of such ammonites as *Knemiceras* and *Douvilleiceras* led Benavides (1956) to conclude that the formation is actually early Medial Albian in age. The fauna of the Chulec Formation in the Central Andes substantiates Benavides' conclusion.

The presence of *Knemiceras* in the lower beds of the Crisnejas Formation of the Northern Andes (Benavides, 1956) and in the lower part of the Chonta Formation in eastern Peru (Kummel, 1948) indicates that these units are equivalent to the Chulec Formation. The common Chulec echinoid, *Holectypus* (*Coenholectypus*) *planatus* Roemer, has been reported from the Arcurquina Formation of Arequipa by Newell (1949), which suggests a possible correlation between the two formations.

The lateral and vertical changes in rock type and faunal composition within the Chulec Formation indicate a marine transgression from the west, in which direction the sea deepened. The lower unit is regarded as littoral or near-shore facies, whereas the upper member indicates slightly deeper-water conditions.

Pariatambo Formation.—The Pariatambo Formation was originally defined by McLaughlin (1924) as the upper member of the Machay Formation, with a type section near Oroya. Following the practice of Benavides (1956) the Pariatambo Formation is regarded as a separate formation in this report.

The Pariatambo Formation is found throughout the Central Andes and much of the Northern Andes of Peru. It consists of a few tens of meters of thin-bedded shale, limestone, and dolomite. Both the carbonates and the shale are bituminous, and dark gray or black in color. The rocks give off a strong fetid odor, even after contact metamorphism.

The upper and lower limits of the Pariatambo Formation are distinct throughout the Central Andes. The black or dark gray color of the formation clearly distinguishes it from the light-colored Chulec and Jumasha Formations.

Chert nodules and veins are found throughout, but show a tendency to be most abundant at the top of the formation. The chert is dark gray, and occurs in nodular bands about 5 cm. thick.

The formation undergoes a marked facies change when traced from west to east. West of the Continental Divide the formation contains a high proportion of black, strongly bituminous, shales. Limestone occurs most commonly as nodules and concretions. The beds of limestone that are present vary in thickness and give the impression that they have formed as the result of the growth of concretions along bedding planes. East of the Continental Divide the formation appears in a calcareous shale-dolomite-limestone facies which is only slightly bituminous. The carbonates occur in regular beds rather than as concretions. Of the five eastern facies carbonate rocks studied in thin section, four are silty, granular dolomites containing shell fragments and foraminifera. The remaining specimen is very fine-grained limestone.

The faunal list of the Pariatambo Formation is as follows.

CEPHALOPODA

Desmoceras latidorsatum (Michelin)*
Oxytropidoceras carbonarium (Gabb)
Oxytropidoceras douglasi Knechtel
Venezoliceras venezolanum (Stieler)
Venezoliceras harrisoni Benavides*
Dipoloceras sp.
Brancoceras aegoceratoides Steinmann
Lyelliceras lyelli (Leymerie) (d'Orbigny)
Lyelliceras pseudolyelli (Parona and Bonarelli)
Lyelliceras ulrichi Knechtel

PELECYPODA

Inoceramus concentricus Parker
Inoceramus salomoni d'Orbigny
Anomia sp. indet.
Exogyra minos Coquand**

Fish scales and teeth

The fauna of the Pariatambo Formation west of the Continental Divide consists principally of ammonites, many of the specimens occurring in calcareous concretions. Some of the shale beds contain numerous compressed specimens of *Inoceramus concentricus*. East of the divide the ratio of pelagic to benthonic forms decreases, and *Inoceramus* and *Exogyra minos* become the most abundant forms.

The Pariatambo Formation of the Northern and Central Andes, the Muerto Formation of northwestern Peru (Fischer, 1956), and the Chonta Formation of eastern Peru (Kummel, 1948) contain the late Medial Albian ammonite, *Oxytropidoceras carbonarium* (Gabb). The sequence exposed at section 2 is probably an equivalent of the formation, for it contains *Lyelliceras*, a genus which is common in the Pariatambo Formation.

The lithologic types and faunal assemblages suggest that euxinic conditions prevailed west of the divide during Pariatambo time, and that the sea shallowed eastward.

Jumasha Formation.—The Jumasha Formation was first described by McLaughlin (1924), and consists of several hundred meters of medium-bedded limestones and dolomites. The formation is topographically prominent and has a characteristic light gray color which facilitates its recognition during reconnaissance work. The main outcrop is restricted to the mountains along the Continental Divide in central Peru, though other, commonly incomplete, sections occur in synclines on the east and west.

Both the upper and the lower boundaries of the formation are conformable. The lower limit is easily discerned, as the medium-bedded, light-weathering limestones of the Jumasha Formation are in contrast to the thinly bedded, dark-colored limestones and shales of the Pariatambo Formation. The upper limit of the formation is placed where the limestone becomes interbedded with marls containing the Celendin fauna.

The average thickness of the Jumasha Formation in the Central Andes is about 400 m. though at section 17, Morococha, and section 20, Oroya, it is less than 200 m. thick. A casual survey of the formation in the strongly folded and faulted region near to the Continental Divide suggests considerable thicknesses, but closer examination reveals that many apparently conformable sequences consist of a series of sheets thrust one above the other.

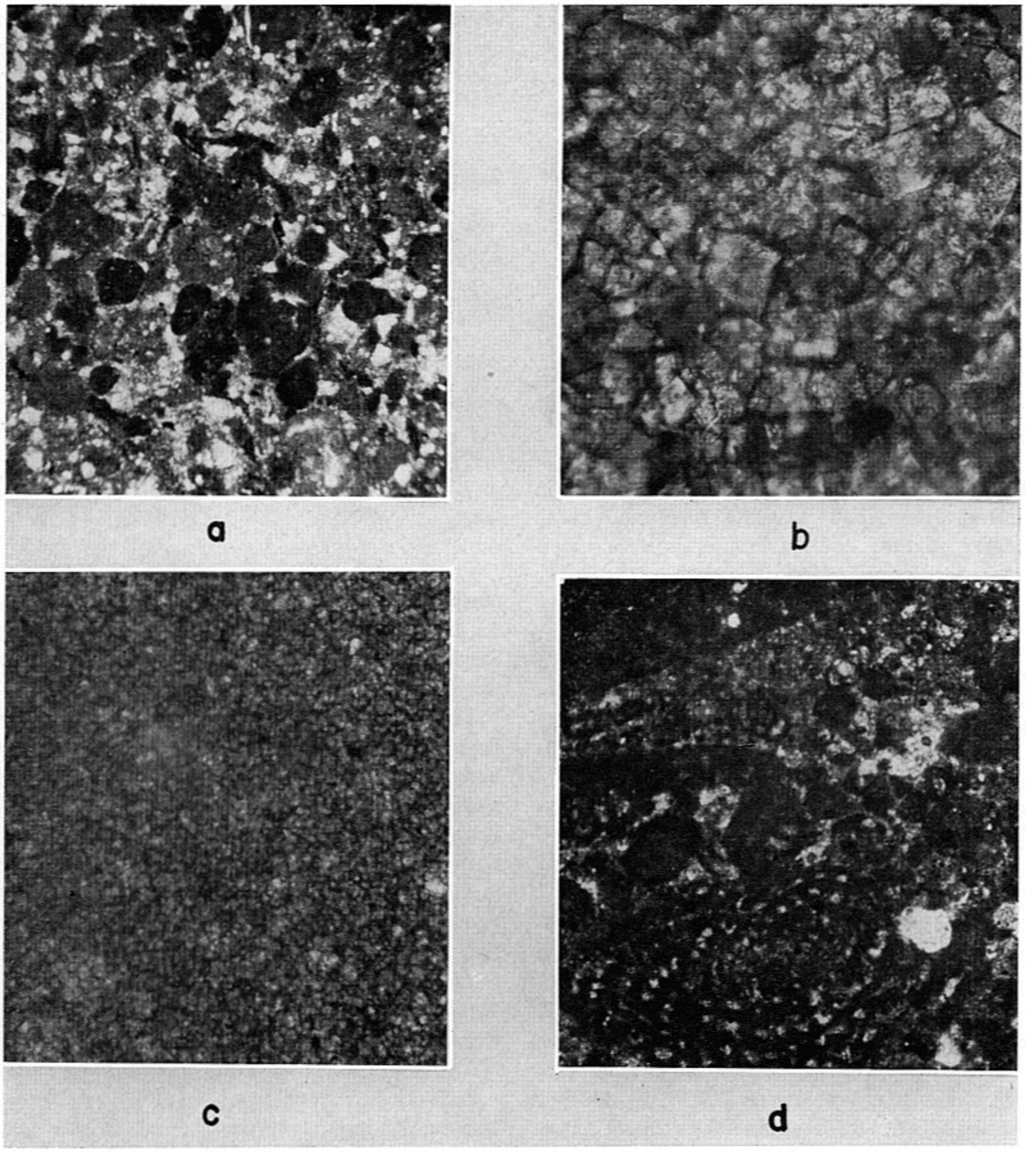
The study of thirty-five thin sections of the Jumasha Formation indicates a variety of limestone and dolomite types. Although there are many intermediate rock types, three main microfacies are distinguished:

Fossil fragmental limestone and dolomite
Pelletal limestone and dolomite
Fine-grained limestone and dolomite

Each microfacies has a wide horizontal extent and lateral facies changes are seldom seen. Vertical gradations are abrupt, however, as the microfacies occur in units as thin as 1 m. The microfacies are described here in order of decreasing importance.

Fossil fragmental limestone and dolomite.—Most of the Jumasha Formation consists of comminuted shell debris set in a matrix of fine- to medium-grained limestone or dolomite (Pl. 2d). Although the majority of shell fragments are unidentifiable, some beds are made up of the unbroken shells of various species of *Exogyra*, *Ostrea*, and *Actaeonella*. Foraminiferal tests do occur, but do not constitute more than 10 per cent of any rock studied. Euhedra of authigenic quartz are commonly present, reaching a length of approximately 0.1 mm.

Pelletal limestone and dolomite.—Several rock specimens were found to consist of small, dark, structureless pellets set in a granular matrix of dolomite or calcite (Pl. 3a). The pellets are mainly spherical, though irregular shapes are also com-



PL. 3.—Photomicrographs of rocks of Jumasha Formation and Celendin Formation.

a. Pelletal dolomite, Jumasha Formation, section 11. Ordinary light, ×30. Fine-grained, roughly spherical pellets set in matrix of fine-grained dolomite.
b. Homogenous dolomite, Jumasha Formation, section 15. Ordinary light, ×270. Consists of very small interlocking crystals of dolomite.
c. Fine-grained limestone, Jumasha Formation, section 18. Ordinary light, ×100. Consists completely of fine-grained calcite.
d. Dolomitic limestone, Celendin Formation, section 6. Ordinary light, ×50. Foraminiferal tests set in matrix of dolomite and calcite.

mon. The size of the pellets is variable, and within a single thin section examples may be found ranging from less than 0.1 mm. to more than 0.5 mm. It is usually impossible to determine the mineralogic character of the pellets, though some of them can be seen to contain dolomite rhombs. One or two thin sections consist of pellets which grade into the matrix without having a distinct boundary.

It is possible that some of the fine-grained limestones are derived from pelletal limestones which have lost all trace of internal structures as a result of diagenesis. Some of the pelletal limestones and dolomites contain oölites, the concentric layering of which is in contrast to the structureless interiors of the pellets. Rocks made up predominantly of oölites are, however, rare in the Jumasha Formation.

Fine-grained limestones and dolomites.—Some beds of the Jumasha Formation consist of fine-grained limestone or dolomite devoid of pellets and shell material. The dolomites occur as yellowish weathering, 1 m.-thick beds which can be followed continuously for more than 2 km. Thin section studies indicate that the rock is made up of interlocking dolomite crystals with a mean length of approximately 30 microns (Pl. 3b). The uniform texture and clear-cut upper and lower contacts suggest that dolomitization occurred penecontemporaneously rather than considerably after the time of deposition.

The fine-grained limestone occurs typically as approximately 1 m.-thick beds which weather to a light gray color. Vertical gradations into bioclastic and pelletal carbonates are common. The rock consists of a mosaic of interlocking crystals which give it a uniform texture (Pl. 3c).

On the east, at sections 6, 9–11, 14, 19–20, and 22, the relative abundance of the various microfacies is as follows:

Fossil fragmental limestone and dolomite	40%
Pelletal limestone and dolomite	20%
Fine-grained limestone and dolomite	15%
Intermediates	25%

Dolomites of all types constitute more than 50 per cent of the formation at these sections. On the west much or all of the formation has been removed by erosion at sections 5, 7, 8, 12, 13, and 16. It is difficult to determine the relative abundance of the various microfacies in these areas, though the following estimate has been made:

Fossil fragmental limestone and dolomite	20%
Pelletal limestone and dolomite	30%
Fine-grained limestone and dolomite	25%
Intermediates	25%

Limestone is more abundant than dolomite at these sections, in contrast to the situation east of the Continental Divide.

Sedimentary structures are uncommon in the Jumasha Formation. Ripple marks are seen in some outcrops, and micro-cross-bedding is found in some of the silty rocks. At section 18 there is an intraformational conglomerate approximately 10 cm. thick, though no other clearly defined examples are known in the formation.

The faunal list of the Jumasha Formation is as follows:

CEPHALOPODA

Lyelliceras ulrichi Knechtel*
Oxytropidoceras douglasi Knechtel*

PELECYPODA

Lima sp. indet.**
Anomia sp. indet.**
Arca sp. indet.**
Exogyra ponderosa Steinmann**

GASTROPODA

Actaeonella sp. indet.**
Natica sp. indet.**

ECHINOIDEA

Bothriopygus compressus Gabb**

The ammonite species indicate that the Jumasha Formation dates from the Late Albian. As the formation is conformably overlain by Santonian, its age range is considered Late Albian through Coniacian.

The stratigraphic position of the Jumasha Formation between the Pariatambo and Celendin Formations is occupied in the Northern Andes by a thick sequence of limestones and shales which Benavides (1956) divided into the Cajamarca Formation, the Quillquiñan Group, and the Puillcana Group. In northwestern Peru the Jumasha equivalent is the Copa Sombrero Formation (Fischer, 1956). The Late Albian through Coniacian sequence in eastern Peru includes part of the marine shales and limestones of the Chonta Formation and their sandy lateral equivalents.

Although the Jumasha Formation is commonly a bioclastic limestone, few of the fossils are whole. The most important genera numerically are *Exogyra* and *Ostrea*, which are the only fossils found in most sections. Benavides (1956) found that in the Northern Andes the limestones and shales equivalent in age to the Jumasha Formation contained an abundant and varied fauna. The rocks of the Jumasha Formation do not indicate any reason why the population should have consisted of so few types. Indeed, the bioclastic limestones suggest that invertebrates may have been abundant. Diagenetic changes may have destroyed many of the fossils, and a further possibility is that scavengers may have broken up much of the shell material. This latter possibility is supported by the following facts: (a) shell debris is abundant; (b) the majority of identifiable fossils are thick-shelled and difficult to break; (c) the current system was apparently weak and unlikely to have been an efficient means of shell destruction; (d) fossils are very abundant in the bituminous Pariatambo Formation, which was deposited in an oxygen deficient environment. As soon as the content of organic carbon decreases the fossil content becomes limited, suggesting that when the bottom waters became aerated scavengers became important.

The Jumasha Formation was deposited in a sea which was shallow enough to permit the growth of extensive banks of *Exogyra* and *Ostrea*. The limestone conglomerates imply that in some areas shoaling took place. There was very little transport of terrigenous material into the Jumasha sea, due possibly to a combination of weak currents and distance from a source area.

Celendin Formation.—The type section of this formation is near the town of Celendin in northern Peru, where it is represented by 255 m. of richly fossiliferous shales and limestones of Coniacian and Santonian age. In the Central Andes a similar lithologic character is found here and there in the same stratigraphic position, directly beneath the redbed formations. Although diagnostic fossils are not common at this horizon in the Central Andes there seems little doubt that the facies represents the Celendin Formation.

In the Central Andes the lower limit of the formation is made where the thin-bedded shales and limestones pass conformably downward into the medium- or thick-bedded limestones of the Jumasha Formation. The contact between the Celendin Formation and the overlying redbed formations is marked by a change in color from cream to bright red, the relationship being one of conformity or slight angular unconformity.

Four thin sections indicate the presence of both limestones and dolomites in the formation. The carbonates are fine-grained or pelletal, and contain varying quantities of shell material and foraminiferal tests (Pl. 3d).

Passing southward the formation appears with reduced thickness at section 9. In the area of section 13 it is seen as a sequence of gray calcareous shales and limestones passing gradationally up into the redbeds of the Pocabamba Formation. In the southern part of the region, section 17 has 115 m. of creamy weathering limestones, dolomites, and calcareous shales which are referred to the Celendin Formation. Between sections 17 and 18 the formation wedges out and at the latter the Jumasha Formation is overlain directly by the redbeds of the Casapalca Formation.

The principal fossils of the Celendin Formation are:

CEPHALOPODA

Barroisiceras sp.·
Tissotia hedbergi Benavides·
Heterotissotia peroni Lisson·
Buchiceras bilobatum Hyatt·
Desmophyllites gaudama (Forbes)·
Texanites sp.·
Tissotia steinmanni Lisson
Tissotia fourneli (Bayle)
Lenticeras baltai Lisson·
Lenticeras lissoni Knechtel·

PELECYPODA

Inoceramus sp.
Lima sp.
Ostrea nicaisei Coquand
Cardium pulchrum Bruggen
Pinna sp.

ECHINOIDEA

Hemiaster fourneli Deshayes
Goniopygus hemicidariformis Bruggen·
Goniopygus superbus Cotteau and Gauthier·

The species of *Tissotia* found in the Celendin Formation in the Central Andes occur only at the top of the sequence at the type section. On this basis the Central Andean Celendin Formation is regarded as a time equivalent only of the upper part of the type section, and is therefore Santonian in age.

The Celendin Formation probably is correlative with the Vivian Formation of eastern Peru, which Kummel (1948) placed in the Senonian on the basis of its stratigraphic position.

The fauna of the Celendin Formation indicates a shallow marine environment. Toward the end of Celendin time circulation became restricted and evaporite beds were deposited locally. Finally emergence took place and redbed deposition commenced.

Redbed formations.—Overlying the Cretaceous marls and limestones in parts of the Peruvian Central Andes are varying thicknesses of nonfossiliferous redbeds with intercalated limestones and conglomerates. The redbeds occur mainly, though not exclusively, east of the Continental Divide. In large areas west of the divide the youngest Cretaceous rocks are Albian, and the redbed formations are poorly represented. In some

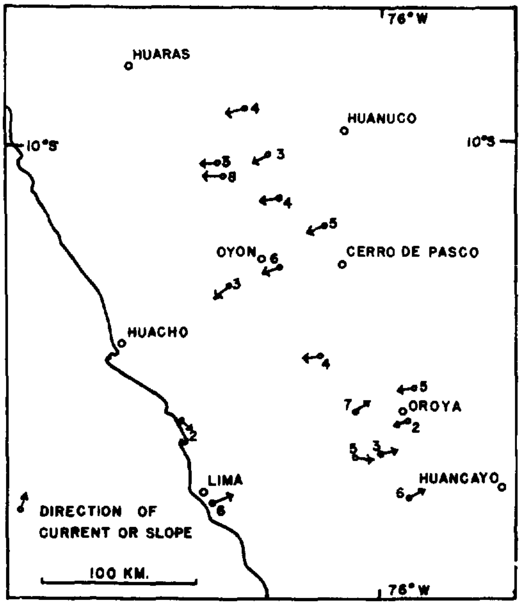


FIG. 6.—Current and slope directions in central Peru during Early Cretaceous.

areas, e.g., on the Continental Divide east of Oyon, the contact between the redbeds and the Celendin Formation is gradational, with interbedding of fossiliferous gray calcareous shales and red siltstones. At the majority of sections, however, the redbed formations are separated from the Upper Cretaceous carbonates by an erosion surface. At Oroya there is an angular unconformity of approximately 5°, though a disconformable relationship is more common.

The top of the redbed formations is rarely seen. The overlying rocks are Lower Cenozoic volcanics which crop out close to the Continental Divide. Farther east the redbeds are commonly the youngest rocks present.

McLaughlin (1924) named the redbeds of the Goyllarisquisga area the Pocabamba Formation. The thick sequences which crop out about the head of the Rimac Valley and on the east were named by him the Casapalca Formation. These formations are at least partly equivalent to one another.

The redbed formations vary greatly in thickness. At the Continental Divide northeast of Canta only a few meters of red conglomerate lie between the Cretaceous limestones and the Cenozoic volcanics. In synclinal basins east of the divide they reach an estimated thickness of more than 1,000 m. Farther east they become thinner and wedge out altogether near the Paleozoic outcrop. Thick redbed sequences occur in eastern Peru, thicknesses of several kilometers having been reported by Ruegg (1949).

Although conglomerates of limestone and quartzite fragments are common, the redbed formations consist mainly of bright red siltstones and fine sandstones. Limestone units are present locally, occurring as white weathering lenticular masses. Volcanics are interbedded with the siltstones of the Casapalca Formation, though they are not common in the Pocabamba Formation.

As the redbed formations have not yielded diagnostic fossils their precise age is unknown. The fact that they are locally interbedded with the Santonian indicates that they are at least partly Cretaceous in age. Where they overlie the Lower Cretaceous they may be even older than Santonian.

On the basis that the redbed formations contain limestones and locally grade down into the Celendin Formation it is possible that they are partly of marine origin. The conglomerates of rounded cobbles are, however, identical with the modern fluviatile deposits of the region, and suggest principally continental conditions for the deposition of the redbed formations.

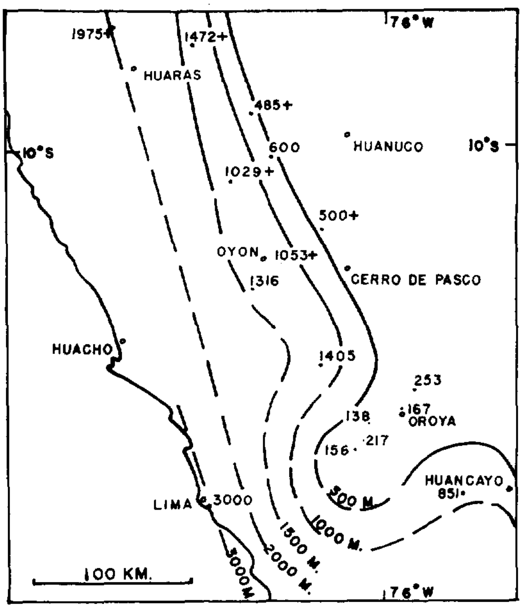


FIG. 7.—Isopach map of Lower Cretaceous formations of central Peru.

SOURCE AREAS OF GOYLLARISQUISGA GROUP

The origin of the clastics which make up the Goyllarisquisga Group of the Northern and Central Andes has not yet been determined. Derivation of tens of thousands of cubic kilometers of clastics is a problem in itself. The fact that orthoquartzites and protoquartzites alone amount to more than 3×10^4 cu. km. indicates that the problem consists not only of determining the origin of a large volume of clastics, but also of accounting for the overwhelming predominance of quartzose sandstones in the group.

Studies of directional sedimentary structures (Fig. 6) indicate that during the Early Cretaceous central Peru had two principal current regimes. A general eastward transport of sediment characterized coastal Peru and the area of sections 17, 18, 19, and 22. In the remainder of the Central Andes currents were directed toward the west. The origin of the westerly derived sandstones is considered first.

Where studies of the Mesozoic of coastal Peru have been made, as in northwestern Peru (Fischer, 1956), and south of Lima (Ruegg, 1957), the Lower Cretaceous or Tithonian has been found on top of folded Lower Jurassic or Triassic formations. On this basis it is believed that parts of coastal Peru were subjected to uplift and erosion during the Medial and Late Jurassic. The Lower Cretaceous clastics of coastal Peru were derived from these tectonic lands.

The problem of the origin of the easterly derived facies of the Goyllarisquisga Group is more difficult, and the location and nature of the source areas remain uncertain. McLaughlin (1924) believed that the Goyllarisquisga Group was derived from the basement rocks of what is now known as the Marañon geanticline. Harrison (1943) also assumed, on the basis of the pebble bands in the Lower Cretaceous, that the source area was nearby. Benavides (1956), on the other hand, suggested an origin in the Brazilian shield. Whereas the Brazilian shield did shed material into the East Peruvian trough, it is unlikely that it contributed significantly to the West Peruvian trough, for the following reason. The Esperanza Member of the Oriente Formation (Kummel, 1948) represents an Aptian marine transgression from the north and west into the East Peruvian trough. Oölitic limestones within the Carhuaz Formation indicate that at about the same time there were marine incursions into the West Peruvian trough (Fig. 11). The Marañon geanticline was not inundated, and evidently stood as a barrier between the two troughs. If this is so, it is difficult to see how sediments from the Brazilian shield could have reached the West Peruvian trough.

Although the shield can not be ruled out as a source of the Goyllarisquisga Group, the Marañon geanticline seems to be more suitably situated. Very little is known of the pre-Cretaceous units of the geanticline. Traverses made by the writer across parts of the geanticline indicate an abundance of schists, phyllites, slates, and graywackes, ranging in age from pre-Cambrian to Lower Paleozoic.

Overlying the basement rocks are Upper Paleozoic formations such as the Mississippian Ambo Group (300 m. of subgraywacke, shale, and conglomerate), the Pennsylvanian Tarma Formation (250 m. of sandstone and shale with intercalated limestones), the Lower and Middle Permian Copacabana Formation (200 m. of limestone and shale), the Upper Permian Mitu Group (variable thicknesses of arkose, red shale, and andesitic volcanics), and the Upper Triassic and Liassic limestones of the Pucará Group. The dirty sandstones of the Upper Paleozoic represent a possible source rock for the Goyllarisquisga Group. The erosion and reworking of these arkoses and subgraywackes, bringing about the elimination of the less stable minerals, could lead to the formation of protoquartzites and orthoquartzites such as characterize the Goyllarisquisga Group. Indeed, in the Pataz area of northern Peru, in the vicinity of the geanticline, the writer has seen Lower Cretaceous sandstones directly overlying units of the Mitu and Ambo Groups.

The sub-Goyllarisquisga clastics found in section 21 may represent a subsidiary source rock of the Goyllarisquisga Group, though the precise significance of these conglomerates and arkoses will not be known until more data are available concerning their extent.

The status of the problem of the origin of the Goyllarisquisga Group may be briefly summarized as follows. It is probable, though not certain, that the source area of the easterly derived facies lay in the geanticline. There is no indication that the older Paleozoic and pre-Cambrian rocks were extensively exposed there during the Early Cretaceous, but the Upper Paleozoic formations certainly contributed. The source of the westerly

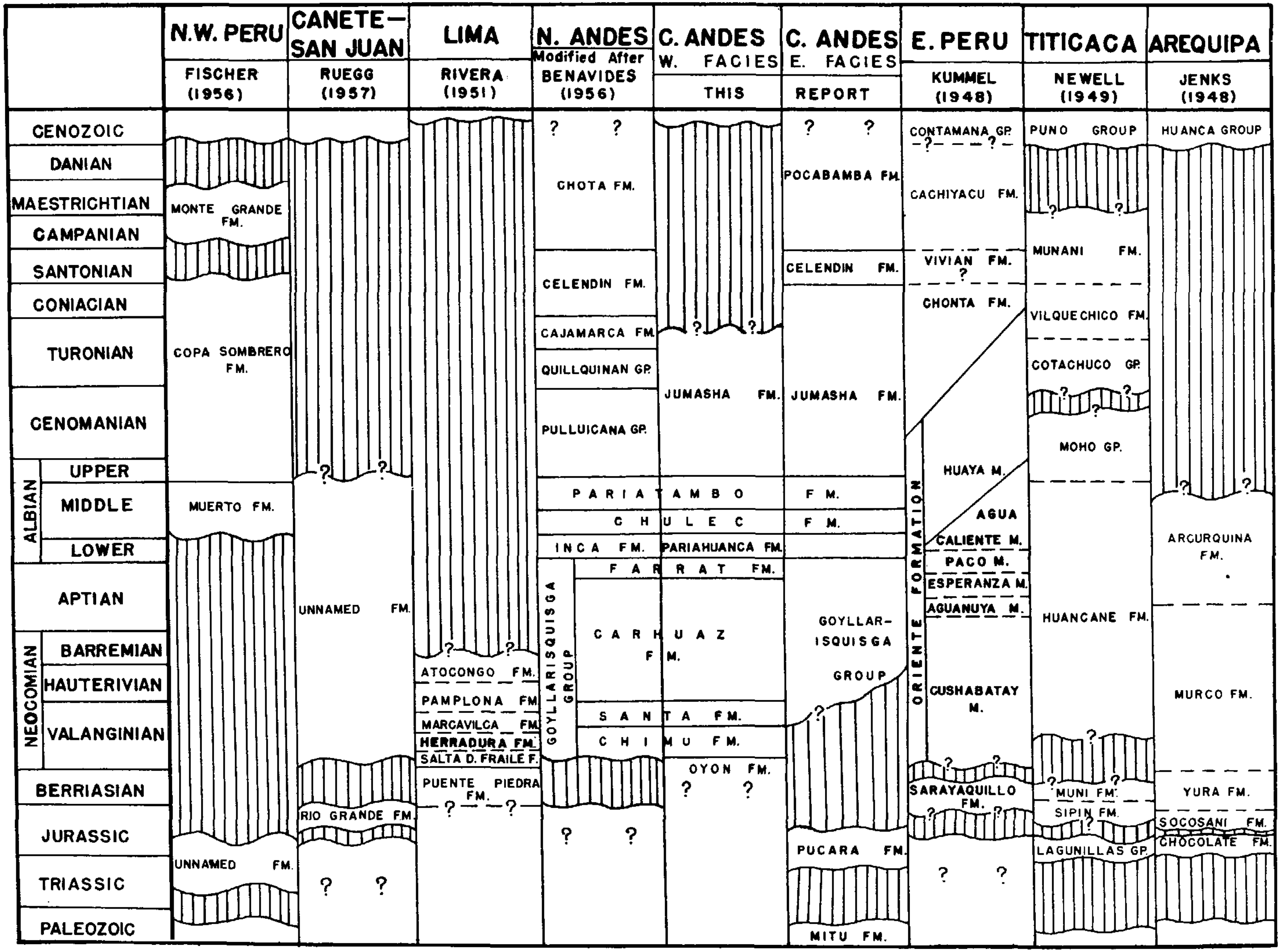


Fig. 8.—Correlation table.

derived facies of the group probably lay in the tectonic lands which were uplifted in coastal Peru by a Late Jurassic orogeny.

Correlation and Stratigraphic Relations of Cretaceous Formations of Peru

Figure 8 shows the age relationships of the Cretaceous formations in central Peru, and their correlation with the Cretaceous formations in other parts of the country.

A major problem lies in the correlation of the non-fossiliferous graywacke-volcanic-shale sequences of the coastal Cretaceous with the Andean sequence of quartzose sandstones and carbonates. Until more paleontological data become available it is impossible to correlate the greater part of the coastal sequence with the Andean formations.

Correlation between the Lower Cretaceous sandstone-shale-limestone sequences of the Andean Region constitute a further problem. Although the Murco and Huancané Formations of southern Peru, the Goyllarisquisga Group of central and northern Peru, and the greater part of the Oriente Formation of eastern Peru are known to be Lower Cretaceous, precise age relationships remain to be ascertained. The oldest diagnostic fossils found in the Cretaceous of these areas are as follows: Late Valanginian in the western slopes of the Central and Northern Andes (Benavides, 1956); Medial Albian in the eastern part of the Western Cordillera in the Central and Northern Andes (Benavides, 1956, and this report); Aptian or Albian in the Arequipa region (Jenks, 1948); and Aptian in eastern Peru (Kummel, 1948). In these circumstances correlation is attempted largely on the basis of lithology and stratigraphic position with respect to dated horizons.

As explained earlier in this report there is a relatively local problem of the relationships between the eastern and western facies of the Goyllarisquisga Group. Benavides (1956) believed that the eastern facies was a lateral equivalent of the Farrat Formation and part of the Carhuaz Formation, but that it lay disconformably on the Santa and Chimu Formations. In the Central Andes it is apparent that the Chimu Formation and the eastern facies of the Goyllarisquisga Group form parts of the same stratigraphic unit. In this report the eastern facies of the group is regarded as a facies equivalent of the Chimu Formation and a time equivalent of much of the Carhuaz and Farrat Formations.

Except in southern Peru the post-Aptian formations of the Andean Region are fossiliferous limestones and shales, the age ranges of which are shown in Figure 8.

Figure 9 shows the inferred stratigraphic relationships of the Cretaceous formations in Peru, and is based on observed field relations and the correlations made in Figure 8. The central parts of sections AB and CDEF represent the writer's concept of the stratigraphic relationships in those areas prior to the erosion of the Cretaceous formations. Although the Goyllarisquisga Group is shown extending with greatly reduced thickness across the axis of the Marañon geanticline, it is possible that the first Cretaceous sediments to be laid down there were facies equivalents of the Chulec Formation.

Tectonic Framework of Andean Belt

From Figures 9 and 10 it is apparent that during the Cretaceous the Andean belt was the site of two linear troughs separated by a relatively positive area.

The West Peruvian trough consists of two large basins separated by a minor arch situated at approximately Latitude 8° South. Both basins subsided at least 3,000 m. during the Cretaceous.

During the Neocomian and Aptian the trough was separated from the Marañon geanticline by a hinge-line which extended in a fairly straight line from about Rio Pallanga to the neighborhood of Celendin. The effect of the hinge-line on the facies and thickness of the Lower Cretaceous formations in the Central Andes is apparent in Figures 9 and 10. The fact that the western facies of the Goyllarisquisga Group is not found east of the Rio Pallanga-Celendin line suggests that the position of the hinge remained constant during much of the Early Cretaceous. The post-Aptian history of the hinge-line is uncertain. Although the Chulec and Pariatambo Formations have slightly different facies on the flank of the geanticline and in the West Peruvian trough, there is no evidence of marked movement along the hinge-line. The straightness and constant position of the hinge-line suggest that it represents a series of faults in the basement.

Southeast of Rio Pallanga there is no clear line of demarcation between the West Peruvian trough and the geanticline. Extending out into

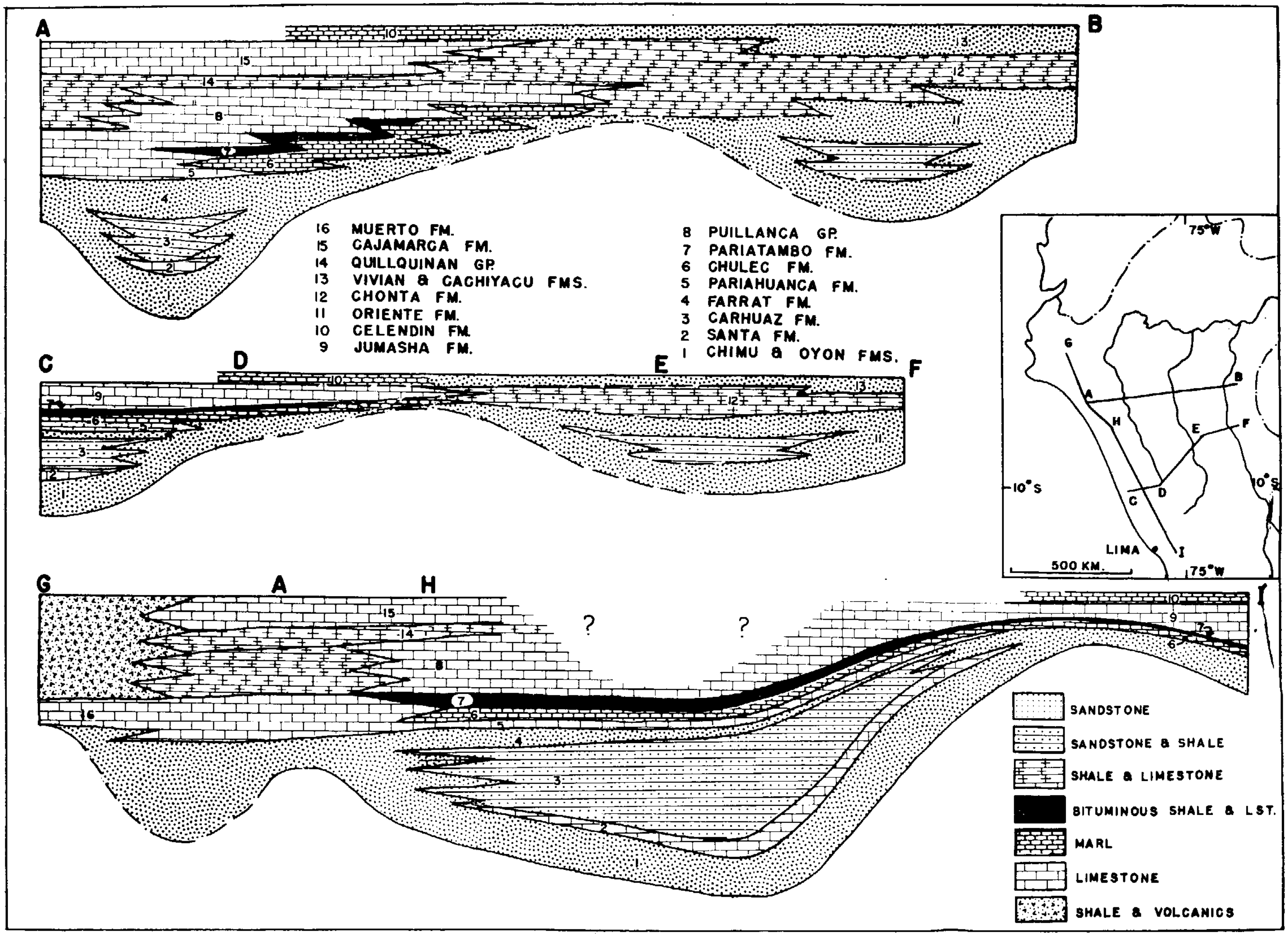


Fig. 9.—Stratigraphic relations of Cretaceous formations of Peru.

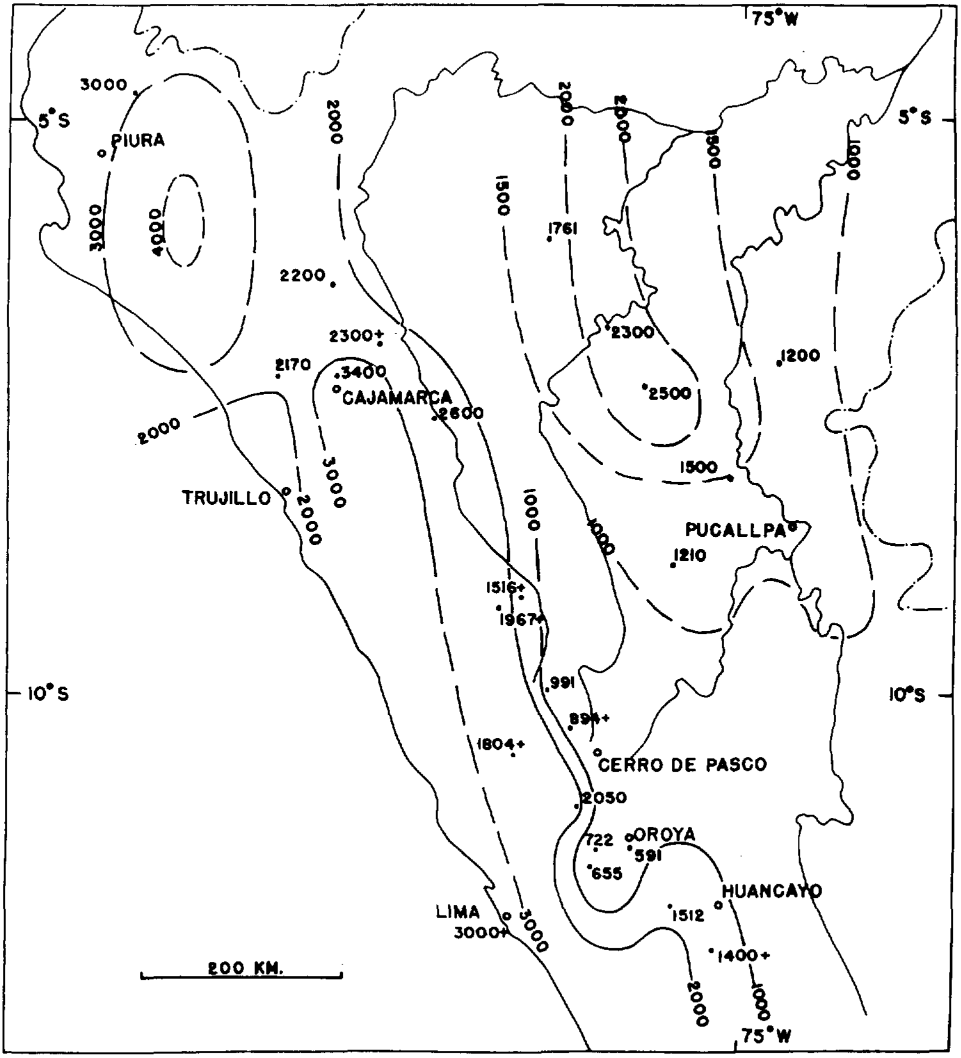


FIG. 10.—Isopach map of Cretaceous formations of Peru.

the trough from the Yauli area is a platform-like prolongation of the geanticline. The western limit of the platform is unknown, for it is covered by Cenozoic volcanics.

Southeast of Yauli the relationships between the geanticline and the trough become even more obscure. On the basis of the similarity between the Cretaceous sequences at Huancavelica (Fernandez Concha, 1952), in the Huancayo area (Miranda, 1956), and at section 22, it appears possible that the trough extended as far east as these areas

The East Peruvian trough was formed by a slight basining of the margin of the Brazilian shield, the maximum subsidence during the Cretaceous being about 2,500 m. The work of Kummel (1948) suggests that the trough merged gradually eastward with the shield. There is no information available on the relationships between the western part of the trough and the Marañon geanticline. The trough continued northwestward into eastern Ecuador, though subsidence there was less than in eastern Peru (Tschopp, 1953). The extension of the trough toward the southeast is known in a general way as far as the Rio Pachitea (Singewald, 1928), from beyond which there is no published information.

Historical Geology

At the end of the Jurassic the Andean belt began to be divided into tectonic units, the positions of which are shown in Figure 3. The oldest units deposited in the West Peruvian trough were the shales of the Tithonian Chicama Formation (Stappenbeck, 1929) and the sandstones which Ruegg (1957) found southeast of Lima. Both these formations are of marine origin. Fischer (1956) found the oldest Cretaceous in the far northwest of Peru to be Albian, indicating that the trough was closed in that direction. Jenks (1948) found Upper Jurassic units in Arequipa, suggesting that the trough extended at least that far southeast.

There was a minor regression at the end of the Tithonian (Ruegg, 1957), followed by the local renewal of marine conditions in the Berriasian, when the volcanics of the Puente Piedra Formation were poured out in the vicinity of Lima. The main phase of subsidence did not begin until the Valanginian, however, when sandstones, shales, and coal seams began to be deposited over a great part of the trough. The clastics in the Lima area were derived from tectonic lands on the southwest, and deposited under alternately marine and non-marine conditions. Non-marine conditions prevailed throughout the eastern part of the trough, where the sandstones and shales of the Oyon and Chimu Formations were deposited.

The corresponding history of the East Peruvian trough has not yet been deciphered. All that can be said is that the trough probably began to subside early in the Neocomian, the initial deposits being the non-marine sandstones of the Cushabatay Member of the Oriente Formation (Kummel, 1948). The Lower Cretaceous sequence in eastern Ecuador is thin (Tschopp, 1953), which may mean that subsidence commenced there later than in eastern Peru. The continuation of the East Peruvian trough to the southeast is known only as far as the Rio Pachitea, from beyond which there is no information available.

In the Late Valanginian the sea transgressed from the west into the West Peruvian trough and deposited the limestones of the Santa and Pamplona Formations. The probable extent of the marine units is shown in Figure 11. Limestones found within the Lower Cretaceous sandstones at section 22 and at Huancavelica (Fernandez Concha, 1952) may indicate that these areas were also submerged at this time. Marine conditions did not, however, extend to the Arequipa region at this time. The source areas southwest of Lima may have been submerged by the transgression, but the fact that marine units extend only to the Rio Pallanga-Celendin line suggests that the Marañon geanticline remained emergent.

By the end of the Early Hauterivian the seas had begun to withdraw from the West Peruvian trough. The disconformity between the Santa and Carhuaz Formations indicates minor erosion at this time, though in the Central Andes sedimentation was continuous.

From the Medial Hauterivian to the end of the Aptian the two troughs accumulated mainly continental sandstones and shales, while the Marañon geanticline continued to act as a barrier between them. The Carhuaz Formation of the West Peruvian trough was deposited in brackish-water swamps which were occasionally inundated by short-lived marine transgressions from the west. The overlying fluviatile sands of the Farrat Formation indicate a regression at the end of the Aptian.

The East Peruvian trough had a similar history. Fluviatile conditions gave way in the Aptian to a minor marine transgression (Kummel, 1948) which gave the Esperanza Member of the Oriente Formation. The advancing sea probably entered the trough by a gap in the geanticline in northern Peru. The transgression was short-lived, however, for the Paco and Agua Caliente Members indicate a return to fluviatile conditions.

While these events were progressing in the two troughs, sediments began to accumulate on the flanks of the geanticline. The deltaic or fluviatile orthoquartzites of the eastern facies of the Goyllarisquisga Group were deposited as lateral equivalents of the sandstones and shales of the Carhuaz Formation. The facies change takes place at about the Rio Pallanga-Celendin line, which must have been acting as a hinge at this time. Conditions on the eastern side of the geanticline remain unknown. The presence of Lower Cretaceous sandstones at the Boqueron on the eastern flank of the geanticline (Ruegg, 1949) suggests a symmetrical distribution of an orthoquartzite-protoquartzite facies on either side of

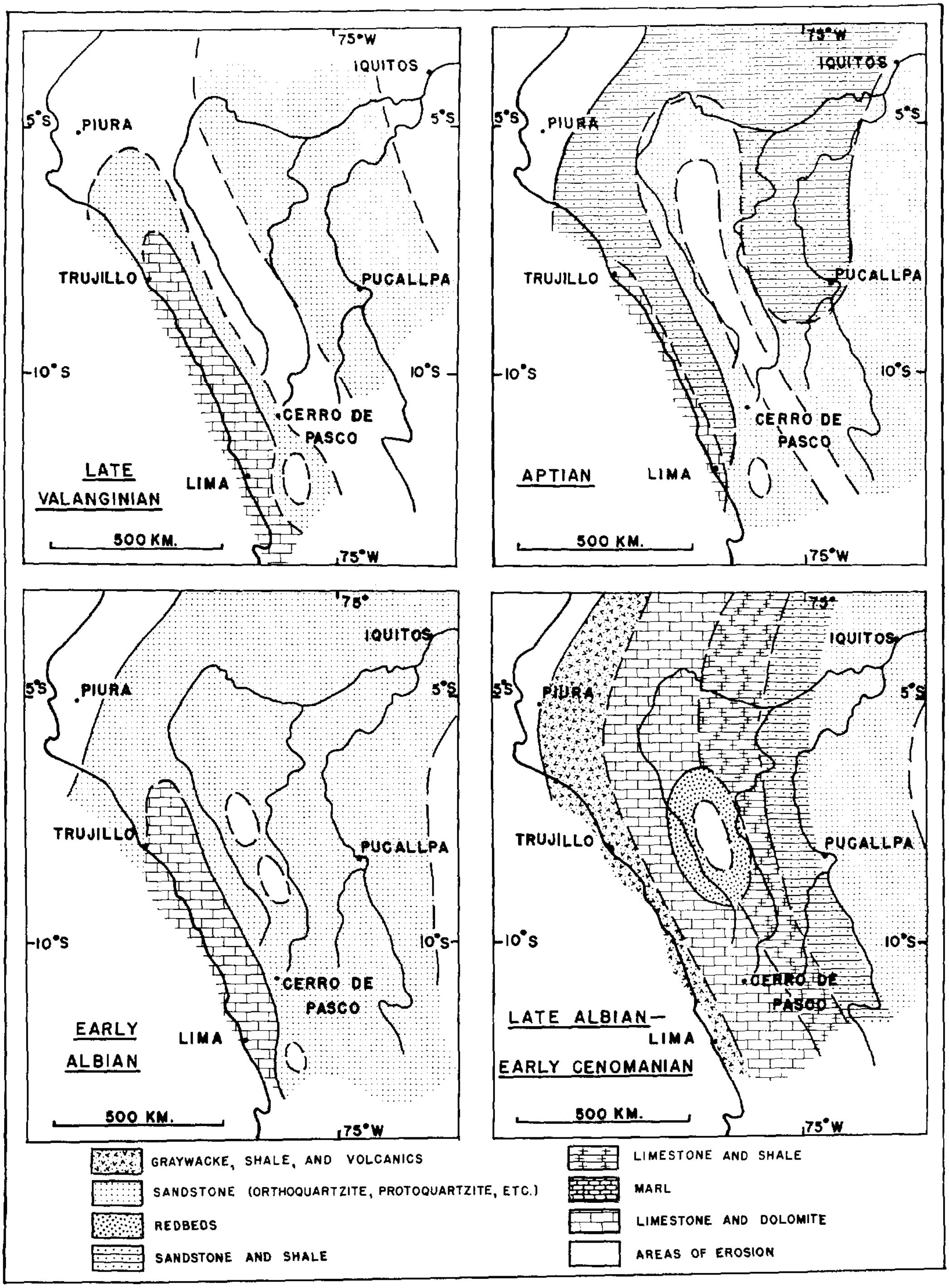


FIG. 11.—Lithofacies maps of northern and central Peru, Valanginian-Early Cenomanian.

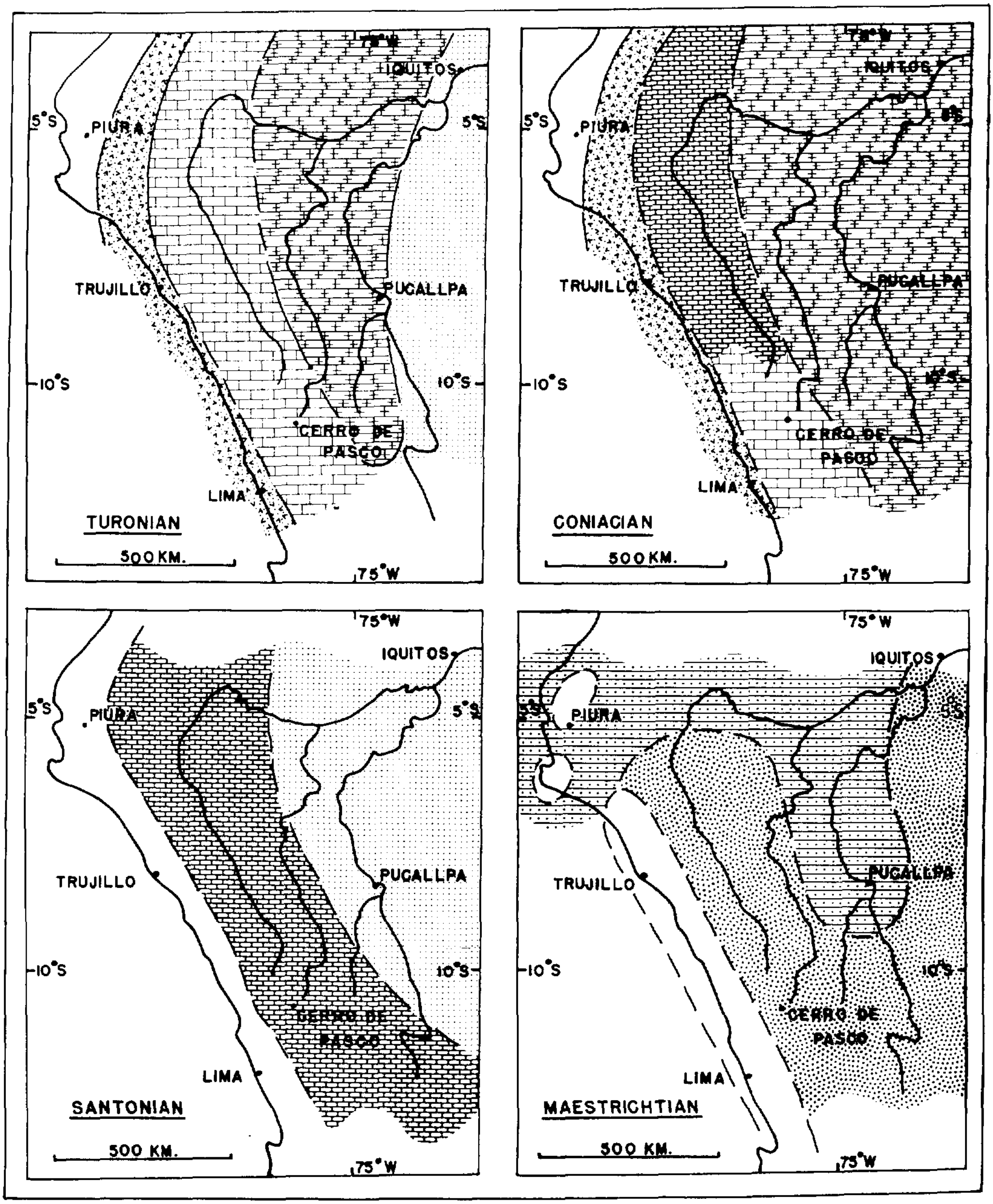


FIG. 12.—Lithofacies maps of northern and central Peru, Turonian-Maestrichtian.

the geanticlinal axis (Fig. 11). The predominantly sandstone sequences on the eastern and western flanks of the geanticline grade respectively into the sandstones and shales of the East Peruvian trough and the West Peruvian trough.

Minor tilting and warping occurred at scattered places within the Andean belt at the end of the Aptian. At section 7, northeast of Chiquian, the Farrat Formation lies with angular unconformity on the Carhuaz Formation, and in northern Peru Benavides (1956) found the Lower Albian Inca Formation disconformably overlying the Aptian.

In the Early Albian there began a marine transgression which eventually extended marine conditions over much of the Andean Belt. At first the sea reached only as far east as the hinge-line (Fig. 11), giving the carbonates of the Inca Formation in northern Peru (Benavides, 1956), the Pariahuanca Formation in central Peru, and the Arcurquina Formation in the Arequipa region of southern Peru (Jenks, 1948). During the Medial Albian most of northwestern Peru and the geanticlinal region became inundated (Fig. 11). The sea reached also into parts of the East Peruvian trough (Ducloz and Rivera, 1956) and into eastern Ecuador (Tschopp, 1953). Continental sandstones continued to be deposited in the central and southern parts of the East Peruvian trough, and in the Titicaca area (Newell, 1949).

Volcanic activity began to be important in the West Peruvian trough during the Albian. Graywackes, shales, and volcanics were deposited in the area of section 2, while interbedded pyroclastics and shales were also being deposited in northwestern Peru (Fischer, 1956) and western Ecuador (Tschopp, 1953).

During the Late Albian parts of the Andean belt were uplifted. The Late Albian-Cenomanian Rosa Formation of Benavides was laid down as an essentially continental deposit resulting from the erosion of an uplifted part of the Marañon geanticline. Benavides (1956) also indicated that the Jequetepeque Valley of northern coastal Peru began to receive clastics at this time. As carbonates were simultaneously being deposited on the east the source of the clastics may have been an uplifted area on the west.

The sea continued its advance during the Cenomanian. In the East Peruvian trough marine conditions spread farther south and east, in which direction the base of the Chonta Formation becomes younger (Ducloz and Rivera, 1956). In the West Peruvian trough the volcanism which began in the Albian continued, thick sequences of shales, pyroclastics, and graywackes being deposited in northwestern Peru (Fischer, 1956). The tuffaceous shales and graywackes of sections 3 and 4 may represent a southward extension of this facies. A fossiliferous limestone in the Moho Group of the Titicaca area indicates that the sea advanced into this region by the Cenomanian (Newell, 1949). There was, however, withdrawal of the sea and some erosion possibly before the end of the Cenomanian, for the Moho Group is followed disconformably by the Cotacucho Group. Continental conditions prevailed in the Titicaca region from the Turonian onward, the Cotacucho Group, Vilquechico Formation, and Muñani Formation being non-fossiliferous continental clastics.

It is not known what conditions prevailed in the Arequipa region during the Late Cretaceous as the youngest Cretaceous deposits found are Albian (Jenks, 1948). The marine Cenomanian of the Titicaca region suggests that marine conditions also persisted in the Arequipa area at least until that time, and possibly until much later in the Cretaceous.

During the Turonian the marine advance reached the Cushabatay area of the East Peruvian trough (Fig. 12). Essentially continental or very shallow marine conditions prevailed in the Titicaca area. Marine conditions persisted over the remainder of the Andean belt in Peru. Limestones predominated in the area of the present Cordillera, while pyroclastics and shales continued to accumulate in northwestern Peru (Fischer, 1956).

During the Coniacian the sea achieved its greatest extent in the East Peruvian trough, reaching east of the Ucayali River into the Contamana Mountains (Kummel, 1948). As the Central and Northern Andes received an influx of clastics at this time, depositing the marls of the Celendin Formation, the greatest advance of the sea in that region may have been pre-Coniacian.

The Santonian was a time of emergence (Fig. 12). The sea withdrew from northwestern Peru (Fischer, 1956), while the continental Vivian Formation accumulated over large areas of the East Peruvian trough (Kummel, 1948). The increasing clastic-carbonate ratio over much of the Andean belt suggests that the sea was withdrawing from that region too.

The influx of terrigenous clastics which began in the Coniacian and Santonian culminated in the general replacement of carbonate deposition by redbed deposition in the Campanian and Maestrichtian (Fig. 12). Although the sea advanced into northwestern Peru and marine-brackish-water sediments accumulated in eastern Peru, the Campanian was essentially a time of emergence. The emergence was more or less complete by the Maestrichtian when marine conditions continued only in northwestern Peru (Fischer, 1956) and in northern Peru (Rivera, 1956).

The shedding of thick, locally conglomeratic,

TABLE I. THICKNESSES (METERS) OF CRETACEOUS FORMATIONS IN CENTRAL ANDES OF PERU

Total Cret-aceous	Oyon	Chim	San	Carh	Fa	Phua	Chul	Pta	Juma	Cel	Redbd	FORMATIONS
	Goyllarisquisga Gp.											SECTIONS
1025+		94+	76	603	30	87	135+					5 Máchac
1212+	485+						138	25	433	131	200+	6 La Union +
768+				534+	80	117	12	25+				7 Aquia
1129+		50+	149	796	34	100+						8 Pomapata
991	600						122	70	174	25	150+	9 W. of Baños +
810+	337+						107	76	290		80+	10 E. of Baños +
1177+	250+						266	44	617		500+	11 Lauricocha +
1804+	98+	487	146	549	36	120	118	50	200+			12 Churin - Oyon
1296+		400+	121	490	42	54	135	34	20+			13 E. of Oyon
894+	280+						107	39	443	25	1000+	14 Yanahuanca +
627+	478						149+					15 Goyllarisquisga +
2050	215+	517	112	496	65	210	198	137	100+			16 Cerro La Viuda
722	138						232	52	185	115	200+	17 Morococha +
655	156						241	47	211		200+	18 Huallacocha +
733+	217						350	86	80+			19 Carahuacra +
591	167						230	59	135		200+	20 Oroya +
480+	253						227+					21 NE. of Oroya +
1512	851						280	44	337		250+	22 Jatunhuasi +

redbed deposits over much of the Andean belt during the Campanian and the Maestrichtian indicates the initial phase of the Andean orogeny (the Peruvian phase of Steinmann, 1929). The distribution and texture of the redbed formations suggests that this phase of uplift was centered in the West Peruvian trough. The erosion products of the tectonic lands were shed eastward, where continental and neritic conditions persisted. The geanticline may also have been uplifted at this time, though strong folding did not occur. Eastern Peru continued to subside, and accumulated great thicknesses of redbed clastics.

At some time in the Cenozoic a more active phase of orogeny commenced (the Incaic phase of Steinmann, 1929). The redbeds and underlying strata were folded and faulted to varying degrees throughout the breadth of the Andean belt in Peru. The precise date of this phase of the orogeny is not known. Newell (1949) suggested a Miocene age for this phase in the Titicaca area. Petersen (1958), however, after a thorough consideration of the uplift of the Andes, concluded that phases of strong folding took place in the Eocene and Oligocene. Following the outpouring of considerable thicknesses of volcanics in various parts of the Andes, the final phase of the Andean orogeny (the Quichuan phase of Steinmann, 1929) probably took place in the Pliocene.

APPENDIX

Owing to restrictions on space the descriptions of the measured sections can not be included in this report. They will be published in the Boletín de la Sociedad Geologica del Peru. However, the sections 1–4 in coastal Peru are given here in abbreviated form, and the Andean sections 5–22 are summarized in Table I. A + sign beside the name of the section indicates that the Goyllarisquisga Group is not differentiated into formations i.e., in the case of the eastern and southern facies of the group.

The abbreviations used in the table for the names of the formations are as follows: Chimu Formation (Chim), Santa Formation (San), Carhuaz Formation (Carh), Farrat Formation (Fa), Pariahuanca Formation (Phua), Chulec Formation (Chul), Pariatambo Formation (Pta), Jumasha Formation (Juma), Celendin Formation (Cel). The redbed formations (Pocabamba Formation and Casapalca Formation) are grouped together under the abbreviation (Redbd).

All thicknesses, both in the descriptions of sections 1–4 and in the Table I, are in meters.

Section 1, Lima

	Thick. (Meters)
Atocongo Formation	
Limestone, gray, medium-bedded	200
Pamplona Formation	
Limestone and shale, dark gray, thin-bedded	200
Marcavilca Formation	
Sandstone, gray white, medium-bedded	298
Herradura Formation	
Sandstone and shale, gray and brown, thin-bedded	666
Salta del Fraile Formation	
Sandstone, brown, medium-bedded	50
Puente Piedra Formation	
Andesitic lavas and breccias, gray-green, well bedded, with yellowish shale member near base	1,794
Total Cretaceous	2,558

Section 2, Chancay

Sill, andesitic, dark gray, massive	20
Graywacke and shale, gray and black, with slump structures	95
Fault	
Sandstone, brown, with shale interbeds, and sill or flow at base	170
Total Cretaceous	285

Section 3, Km. 254, of Panamerican Highway

Feldspathic graywacke and agglomerate, interbedded with dark shale	700

Section 4, Km. 315 of Panamerican Highway

Graywacke, andesitic tuff and agglomerate, and dark shale	1,586

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